Newsletter of the Climate Variability and Predictability Programme (CLIVAR)

Exchanges

No. 26 (Vol. 8, No. 1) March 2003

WOCE-CLIVAR Transition

Latest CLIVAR News

- Welcome to Katy Hill, our new ICPO staff member: Visit her under: www.clivar.org/organization/icpo/hill.htm
- The CLIVAR literature section on the web has been expanded substantially. Entries of CLIVAR relevant literature of more then 20 journals are now available. In addition, listings sorted by Principal Research Areas are available as well. Visit: www.clivar.org/publications/journals/.
- The WOCE Atlas Series: subscribe to this unique display of the WOCE results (page 6).

Visit our news page:
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The Future of *In Situ* Climate Observations for the Global Ocean

A global ocean observing system is a key element for the success of climate research in the future. CLIVAR and other programmes will build on the accomplishments of the World Ocean Circulation Experiment (WOCE) that developed key elements of this system, such as the global array of profiling floats, Argo (see the figure below).

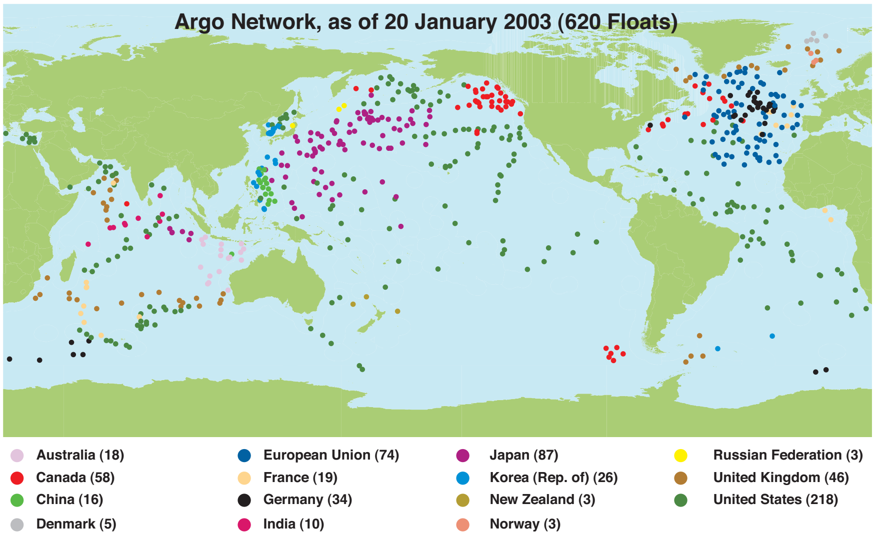

Figure 1 from the paper 'The Future of In Situ Climate Observations for the Global Ocean' by Dean Roemmich and John Gould: Positions of 620 presently active Argo floats, as of January 20, 2003. (http://argo.jcommops.org). The article on the Argo system can be found on page 4.

Call for Contributions

We would like to invite the CLIVAR community to submit papers to CLIVAR Exchanges for the next issue. The overarching topic will be on **science related to CLIVAR Africa.** The deadline for this issue will be announced through the CLIVAR webapge (see below).

Guidelines for the submission of papers for CLIVAR Exchanges can be found under: http://www.clivar.org/publications/exchanges/guidel.htm

CLIVAR is an international research programme dealing with climate variability and predictability on time-scales from months to centuries.

CLIVAR is a component of the World Climate Research Programme (WCRP).

Editorial

Dear CLIVAR Community,

This issue

Within the World Climate Research Programme (WCRP) a second major project has been finished successfully. A few years after TOGA (Tropical Ocean Global Atmosphere), the World Ocean Circulation Experiment (WOCE), started in 1988, was formally closed at the WOCE conference in San Antonio, USA last November. WOCE was a unique experience and its legacy encompasses a comprehensive global ocean data set, a complex but effective data management system for quality controlled ocean observations with highest accuracy and new observational techniques, and overall a vastly better understanding of the world ocean. Although the major aim of WOCE was a better understanding of the ocean's mean state, a lot has been learned about its variability as well. Here CLIVAR comes into play and will continue some of the WOCE activities through its basin-scale projects in the Atlantic, Pacific and Southern Oceans as well as through global sustained observations and modelling activities. In the latter category the former WOCE/WGCM Working Group on Ocean Model Development is now reporting to WGCM and CLIVAR.

In order to acknowledge the accomplishments of WOCE and to look forward to continuation and expansion under CLIVAR, this issue of Exchanges is dedicated to the transition of WOCE to CLIVAR. Some of the perspectives presented at the final WOCE conference are summarized in the contributions to this newsletter. In addition, progress reports of a number of CLIVAR projects and panels as well as related activities are provided.

Katherine & Katherine – staff changes

Within the ICPO, we are grateful to welcome Katy (Katherine) Hill as a new staff scientist focusing on CLIVAR Pacific and carbon issues. Katy who started in November got her BSc at the University of Southampton and her MSc. at the University of Victoria, Canada. Welcome to CLIVAR Katy! At the end of last year Katherine Bouton left the ICPO. Katherine was responsible for data management and our searchable data base SPRINT. Thank you Katherine for all your hard work and all the best for your new job at the University of Reading!

2003 – 5 years of CLIVAR implementation

Depending how you count, 2003 will the 5th year of CLIVAR, since the implementation of the programme started about 5 years ago at the CLIVAR conference in 1998. Thus, we are preparing to review this first pentade at the CLIVAR conference in June 2004. Many parts of the programme have already shown considerable progress, others are coming to speed right know. It is a huge task for us at the ICPO to keep track of all activities, scientific progress and actions required to move forward. Our aim is to facilitate and advance the scientific progress with a minimum of bureaucracy and overhead. Although it might not always easy to fully accomplish this goal, the multiple information and communication fora, like publications, websites, working groups and panels provide useful tools for the community to benefit from an organization like CLIVAR. CLIVAR might be a huge puzzle with lots of bits and pieces but we hope to assemble it within the lifetime of the programme to a comprehensive new picture of climate variability. You, the scientific community are the key part of it, without your new results and theories, we won't be able to get all these pieces together.

Exchanges in 2003

The scope and format of our newsletter Exchanges has been expanded over the years. As well as reporting from the increasing number of CLIVAR panels, working groups and projects, Exchanges has increasingly published scientific results of CLIVAR-related research. This has been done through publication of more than 120 science articles to date. This increasing interest, along with a steadily increasing number of subscribers, means that it requires more and more resources to produce the newsletter. On the other hand, the difficult financial situation which a number of countries are facing has led to a reduction in the funding available to the ICPO to produce the newsletter. As a consequence we are currently not able to publish all of the papers and articles received in hardcopy form. For this issue we put the main emphasis on the science aspects of the WOCE-CLIVAR transition. Thus almost all other contributions, including reporting on past meetings and related projects, plus one or two science articles, are only available from our website. A listing of these articles can be found on page 36. Please visit http://www.clivar.org/publications/exchanges/ex26/supplement/ to download these papers. We are currently exploring options for the mode of publication of future issues of Exchanges. In the meantime, we apologize for any inconvenience.

Overall, we hope to continue to further develop Exchanges as a lively and integral part of CLIVAR and climate research in general and to maintain the present rate of publication of 4 issues per year.

Andreas Villwock

The final WOCE conference – the end of one era and the start of another

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San Antonio, Texas is not a place that is noted for its oceanographic connections, but for a week in late November 2002 it hosted a gathering of marine and climate scientists at a conference "WOCE and beyond" marking the end of the World Ocean Circulation Experiment (WOCE). In the almost 20 years that WOCE has been part of the World Climate Research Programme our ability to observe and model the oceans at global scales underwent a revolution and our knowledge of the oceans' role in the climate system is much more quantitative than before.

The conference was structured around plenary talks each morning that addressed for a number of subject areas "What were our capabilities when WOCE started? What have we learned during WOCE? and What are the outstanding issues that remain to be solved?" The afternoons were largely devoted to poster sessions.

There were many compliments paid at the end of the week several of which were in the vein of "That was the best conference I have ever attended" - and these comments were from people who had been to MANY conferences.

So, what made it so special?

First and foremost, the extremely high standard of the plenary talks. Each speaker had worked with a team of scientists to try to ensure that the talks gave more than a personal perspective. Despite misgivings on the part of some speakers who had never given a Powerpoint presentation before, all the talks were back-projected onto large screens either side of a central podium. That worked well, thanks to some guidance and adjustment to some presentations from the staff of the US WOCE Office. The graphics were excellent but the large conference hall did not lend itself to questions from the floor. To compensate there was lots of discussion around the posters - helped, for those who wanted it, by free beer. On a less scientific note, it was (maybe) the last chance for WOCE scientists, young and old, to get together in pleasant surroundings, to reminisce about the past and to plan for the future.

Several of the papers that appear in this edition of Exchanges are based on plenary talks and poster presentations from the conference. All, to a greater or lesser extent, focus on our ability to document the state of the oceans and its temporal variability – key elements in understanding the oceans' role in climate. The papers describe measurement and state estimation on both global and local scales (the tantalising observations of temperature rise in Antarctic bottom water as it enters the S Atlantic – is this linked to rising atmospheric temperatures?) Novel integral measurements of the properties of the ocean using acoustic methods are described. Others cover the achievements (and limitations) of low resolution climate models .

With WOCE now ended as a WCRP project, CLIVAR needs (along with all its other responsibilities) to fully embrace the development of observations and models of the global ocean. We cannot afford to lose the momentum that was generated by WOCE.

An area that certainly must not be neglected is the ocean community's need to document, quality control, exchange and archive ocean measurements. CLIVAR must have a strategy that will enable the data collected by WOCE to be supplemented and enhanced while fully utilising the exciting potential for distributed data systems and while still maintaining the highest data quality needed to detect subtle but important changes in the ocean.

WOCE has finished as part of the WCRP and has passed to CLIVAR many responsibilities - but it has also opened up for CLIVAR many exciting new prospects.

Beyond San Antonio

The figures from all of the plenary talks can be downloaded from
http://www.woce2002.tamu.edu/agenda.html

A major achievement was the distribution to each conference attendee of a copy of the final WOCE data resource DVDs. These contain a remarkably complete and high quality data set plus all the relevant metadata. The data are also available on line at
http://www.nodc.noaa.gov/woce_v3/.

Since the conference the WOCE IPO has printed "WOCE Observations 1990-1998- a summary of the WOCE global data resource". It is brief guide to "What was measured?, Where?, When? and by Whom?". At the time of writing it is about to be mailed and is available online at http://www.woce.org.

A great deal of interest was generated at the conference by the first mockup of the WOCE Atlas volumes that are now being compiled ready for printing later this year. You can view the contents and some sample plates at http://www.woce.org/atlas_webpage/

The future of *in situ* climate observations for the global ocean

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Introduction

Global ocean observations for climate research are a major part of the legacy of TOGA and WOCE, and a major element of CLIVAR. TOGA demonstrated that an integrated observing system spanning the tropical Pacific led to better understanding of El Niño/Southern Oscillation variability and to successful El Niño predictions. WOCE, with a one-time global survey, quantified the oceans' contribution to the total heat budget of the climate system through heat transport as well as heat storage. To build on the legacies of WOCE and TOGA, CLIVAR will include two classes of *in situ* ocean observations. Limited duration regional process studies will focus on phenomena that are poorly understood in order to improve their representation in ocean and coupled models. Sustained observations on basin-to-global scales, which are the topic of this note, should resolve the patterns of climate variability and the large-scale climate processes that the models aim to simulate.

The CLIVAR Ocean Observations Panel (COOP) and the Ocean Observing Panel for Climate (OOPC) jointly undertook to develop and summarize a community consensus on the design of an ocean observing system through the OCEANOBS99 Conference (Koblinsky and Smith, 2001). Planners were required to consider practicality and resource limitations for every element of the observing system, as well as technical feasibility. The planning process was broad in scope, including satellite measurements, *in situ* observations, and the data assimilation systems needed to synthesize them. The present note is narrower, to review the substantial progress made since OCEANOBS99 in several elements of the *in situ* observing system, as well as to point out the major challenges that lie ahead for this endeavour.

Objectives of global ocean observations for climate

The primary elements of the climate system are the heat and hydrological cycles. Climate observations and models should be capable of tracking heat and water through the ocean/ atmosphere/cryosphere system, including understanding how radiationally active elements modulate such transfers. The specific objectives for sustained large-scale ocean observations are to:

- *Provide a basic description* of the physical state of the global ocean, including its variability on seasonal and longer time-scales.
- *Reveal large-scale processes* that influence climate.
- *Provide the large-scale context* for regional process studies.
- *Produce the required datasets* for data assimilation and (seasonal and longer) forecast model initialization.
- *Complement the satellite remote sensing systems* with data needed for validation, calibration and interpretation.

Status of implementation

The ENSO Observing System – TOGA's legacy. The ENSO OS was the prototype for basin-scale integrated observing systems. It initiated sustained observations in the tropics, including the TAO/TRITON mooring array, broad-scale XBT, surface drifter , and sea level networks. All of these networks are now maintained, with the latter three extended to extra-tropical coverage. The ENSO OS also pioneered real-time public data delivery in order to serve the needs of a broad user community with both research and operational objectives. The successes of the ENSO OS, in better understanding ENSO variability and successful seasonal prediction, and its continuity, have paved the way for global observations to build on its capabilities.

The Argo Network. The Argo global float project collects temperature/salinity profiles and mid-depth velocity measurements on broad spatial scales over all of the world's ice-free deep oceans. Argo will provide near real-time measurements of heat and freshwater storage, plus large-scale circulation and transport. By January 2003 (Figure 1, page 1) Argo had achieved over 20% of its target of 3000 operating floats, and there were substantial float arrays in all of the ocean basins. There are commitments for most of the floats needed to complete the Argo array, and by 2006, Argo plans to collect about 100,000 temperature/salinity profiles and mid-depth velocity measurements annually. This is double the number of XBT profiles collected annually during WOCE. Argo floats are supplied and deployed by many nations (Figure 1), with coordination by the international Argo Science Team. Argo data are publicly available in near real-time from either of two global data assembly centres. The Argo Project has overcome some early technical problems in float designs, and deployments are now increasing rapidly. Scientific analyses and operational usage of Argo data have begun and will be reviewed at a symposium in November 2003.

Repeat Deep Ocean Hydrography. During the 1990's, WOCE obtained a global baseline survey of the oceans - from top-to-bottom and including geochemical tracers. There are now commitments to repeat many of the WOCE lines (Figure 2, page 17) in part motivated by a resurvey of global CO_2 inventories. Reoccupying these transects every 5-10 years will make it possible to investigate variability in water mass inventories, physical and biogeochemical properties, and renewal rates. The data will help to reveal the nature of deep ocean circulation variability, of long time-scale fluctuations in the deep meridional overturning circulations, and the corresponding transports of heat and freshwater.

Time-Series Stations. Time-series observations at fixed points are an important complement to the broad-scale arrays such as Argo. This is because they may occupy special locations, sample at high frequencies, and include a wide variety of physical and biogeochemical parameters. Time-series stations include several distinct types of platforms: the tropical moored networks (TAO/TRITON and Pirata), transport measurements at special locations such as choke points and western boundary currents, mid-ocean full-depth observatories for water properties (e.g. the Bermuda and Hawaii stations), and air-sea flux reference stations. While considerable progress has been made in evolving a community plan (Figure 3, page 17) and building support for time-series stations, including the development of autonomous moored profilers, a considerable part of the plan remains uncommitted.

Other observing system elements. While the above list includes the largest elements of the *in situ* ocean observing system, others are also important for balanced and comprehensive sampling. As noted above, the surface drifter network, broad-scale XBT network, and sea level network have all been extended beyond the tropics to coverage that is quasi-global. Some additional expansion is needed – for example the drifter network will increase from about 800 active drifters today to 1100. XBT networks include High Resolution XBT/XCTD (HRX) sampling in all of the oceans, with a selected set of repeating transects to observe variability in upper ocean circulation and transport on spatial scales ranging from boundary currents and eddies to basin width. Pacific HRX transects have been sampled on a quarterly basis for up to 17 years (http://www-hrx.ucsd.edu). Acoustic tomography and thermometry offer great potential for integral measurements over regional-to-basin scales, and a number of regional arrays are planned in the near term.

Major challenges

The most obvious challenge is to obtain resource commitments from many countries to implement and sustain the observing system long enough to demonstrate its capabilities and its value. However, there are several other substantial challenges to be faced for success in this endeavour.

1. Completeness of the system: what is missing? In the OCEANOBS99 process, boundary currents were singled out as a crucial part of the circulation for which a systematic plan was not yet available (Imawaki et al., 2001). At present there is still no overall plan for measuring the oceans' boundary currents – the low-latitude, subtropical, and subpolar western boundary currents, as well as the eastern boundary currents. Several different techniques are in use or planned for boundary current measurements in a few specific locations – moored transport arrays, HRX transects, tomography, and repeat deep ocean hydrography. These approaches are valuable but not sufficient, and will leave many unmeasured flows that contribute critically to ocean circulation and transport. New technologies of gliders and other autonomous vehicles offer the potential to measure the oceanic boundaries efficiently. For example, one possible glider sampling scheme is shown in Figure 4 (page 18). Gliders are slow - about 20 cm/sec - so this plan exploits the swift flows in the upper 1-2 km of the boundary currents to advect the instrument downstream as it glides across. By making multiple crossings, and having several gliders simultaneously in different parts of the current, the evolving four-dimensional structure of the flow is measured. Transects might coincide with Jason-1 altimetric tracks in some places. The plan shown in Figure 4 would require substantial local logistical support for repeated deployment, recovery, servicing and shipment of instruments.

2. Biogeochemical measurements. Deep-ocean hydrography and time-series stations have been the starting points for adding appropriate biogeochemistry to the physical observing system. Many new autonomous sensors are possible for float, drifter and mooring applications, and a few have been demonstrated. The challenge will be to select and implement those sensors that increase the value and completeness of the observing system and are compatible with the existing missions of autonomous instruments. Broadening the observing system to increase its multi-user aspect is a crucial selling point, but careful judgements are required for initiation of any new long-term observations.

3. The co-evolution of the observing system with models. We are counting heavily on models to be the tools that enable full integration of global satellite and *in situ* observations. It is essential that the evolution of the observing system and that of data assimilation systems and forecast models be harmonized. The roles of observations must be to provide appropriate data and statistics for data assimilation and model initialization, provide independent information for testing model results and model processes, and discover new phenomena not anticipated in models – thereby stimulating model improvement. A clear need is for global subsurface data sets to complement the coverage of satellite measurements of the sea surface.

4. The research/operations interface. A definition of operational oceanography is: its objectives and characteristics can be specified in advance, it has an indefinite operating life and evolves cautiously, and its success is judged by contributions with public benefits. By this definition, the TAO/TRITON Network is operational. For implementation, development and maintenance of the complete observing system, a strong partnership between research institutions and operational agencies must be created. A continuing strong leadership and participatory role is required of research institutions to assure the high quality and technical evolution needed in ocean observations for climate. The observing system needs to have vertical integration (instrumentation development, network design, implementation, data management, scientific analysis, data assimilation) as well as horizontal integration across the observing system elements.

5. Data and information management. In order to serve the needs of multiple users, data management and delivery systems are becoming increasingly sophisticated and versatile. For example, the Argo Data System must provide both near real-time data for operational applications, and a scientifically reviewed dataset for research. Argo Global Data Assembly Centres merge the data from all national data centres and maintain "best copy" profile data – including quality control flags and histories - plus trajectory data and metadata.

Conclusion

Clearly, the work of designing, implementing and evolving the ocean observing system has just begun. The work will go on with or without an active CLIVAR voice, but CLIVAR clearly has a vital stake in the process - to ensure the scope and quality of data and the progression of technology, so that climate science can be a primary user of the observing system. Climate is intrinsically a global problem, and CLIVAR must clearly enunciate its global focus and assert its role in building and maintaining global ocean observations.

References

Koblinsky, C., and N. Smith, (Eds.), 2001: *Observing the Oceans in the 21st Century*. Bureau of Meteorology, Melbourne Australia.

Imawaki, S., W. Zenk, S. Wijffels, D. Roemmich, and M. Kawabe, 2001: Oceanic boundary currents. In: C. Koblinsky and N. Smith, eds.: *Observing the Oceans in the 21st Century*. Bureau of Meteorology, Melbourne Australia.

The WOCE Atlas Series

- The WOCE Atlases will be the definitive atlases of the physical and chemical properties of the oceans
- Four atlas volumes covering the Southern, Pacific, Atlantic and Indian Oceans
- Each volume contains
  - vertical sections of up to fifteen parameters along the WOCE one-time lines
  - horizontal property maps on depth and density surfaces
  - property-property plots
  - electronic version of the atlas on DVD with additional parameters, depth and isopycnal maps
- Publication starting late 2003
- See sample sections at http://www.woce.org/atlas_webpage/
- Estimated cost will be as little as $50 per volume thanks to support from BP

If you are interested in purchasing one of these atlases please email Mrs Jean Haynes (jchy@soc.soton.ac.uk) so we can define the print run. There is no commitment at this stage.

Do simplified climate models have any useful skill?

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Numerical models are important research tools in climate dynamics because they permit the quantitative testing of hypotheses regarding mechanisms of climate change. The importance of the deep ocean circulation for climate variability and rapid climate change was recognized some 40 years ago by Henry Stommel (Stommel, 1961), because dynamical ocean components need to be included in climate models. This requirement posed a serious challenge to the modellers, because now adjustment processes associated with the deep ocean needed to be included in these models. Simulation times thus increased from a few decades to centuries and millennia. More importantly, it introduced significantly more degrees of freedom into these models with unexpected consequences such as climate drift, multiple equilibria and many others.

There are several ways to take this challenge. First, the early development has focused on coarse-resolution models of the coupled atmosphere-ocean system. The representation of fundamental processes was limited in these models with the consequence that unrealistic flux corrections had to be used to stabilize simulations. Although these involved local sources of heat, freshwater and momentum, many useful predictions could be made that fuelled scientific development and shaped our thinking (e.g. Manabe and Stouffer, 1988). Over the last decade, with the growing availability of computing power, the grid resolution of these models has been steadily refined, and the parameterisations of important processes have been improved: flux corrections are no longer necessary in current coupled models (IPCC, 2001). One might therefore be tempted to conclude that the days of coarse-resolution models are over. This would be premature, however. Both paleoclimate research and the study of natural climate variability and climate sensitivity still depend heavily on climate models of comparatively low resolution. If used judiciously, they continue to contribute significantly to the scientific progress.

A second possibility is the development of simplified models. Usually, such models are derived from the full set of equations by suitable averaging processes. Energy balance models of the atmosphere (Sellers, 1969), the radiative convective models (Manabe and Wetherald, 1967), the Lorenz model (Lorenz, 1963), and the Stommel box model for the thermohaline circulation (Stommel, 1961) are extreme examples of such rigorous averaging. In spite of their limitations, it should be recognized that these models represented key steps towards an understanding of the Earth system and have been very useful in elucidating some fundamental concepts such as climate sensitivity, near-constancy of relative humidity in a warming world, multiple equilibria of fluid flow regimes, and principles of predictability in the climate system. Both the Lorenz and the Stommel models are important examples of how extremely simplified models can change completely our view of the climate system. The skill of these types of models does not lie with their ability to make specific climate predictions, but with the potential to demonstrate fundamental dynamical concepts which subsequently must be tested with more complex models. Furthermore, these models permit exploration of parameter space in a systematic way. In essence, such models only make sense within a *hierarchy* of models, with which a thorough investigation of processes is possible. Table 1 (page 8) shows such a hierarchy of models ordered according to the number of simulated dimensions in ocean and atmosphere, respectively.

The third possibility is to accept certain compromises regarding the model complexity. This is illustrated by models that populate the centre of this model hierarchy (grey shading in Table 1). These models of reduced complexity involve more processes and dimensions than the simplified models mentioned above, but they are still orders of magnitude simpler than general circulation models. Due to their low computational burden, these models have become increasingly popular in the last few years. This is manifested by special sessions at conferences, the proposal of intercomparison projects, and ongoing activities in many institutes worldwide. These "coupled models of intermediate complexity" (Stocker et al., 1992b), now referred to as *Earth System Models of Intermediate Complexity* (EMICs) (Claussen et al., 2002), are convenient research tools especially for paleoclimatic modelling and ensemble simulations of future climate change. It must be emphasized, however, that such simplicity is equally tempting and treacherous. Application of these models and interpretation of the results requires experience and caution because of the many implicit limitations in terms of their dynamics.

More than in comprehensive models, simplified models must use parameterisations with tunable parameters. Such tuning is dangerous and conclusions must be independent of small changes to such parameters. The real goal for these models is not only to reproduce certain observations or paleoclimatic records as perfectly as possible, but to make *testable predictions* about the dynamical behaviour of the climate system, e.g., the response of the southern hemisphere to a reduction of the Atlantic thermohaline circulation, (Stocker et al., 1992a). In addition, these models are very useful to construct ensemble simulations. With such ensembles, uncertainty in climate change projections can be quantified in an objective way (Knutti et al., 2002).

Table 1: Climate model hierarchy. This is only a "projection", since complexity in components such as the cryosphere, land surface and the biogeochemical cycles is not displayed here. Coupled models of reduced complexity (Earth System Models of Intermediate Complexity, EMICs) are shaded in grey. Specific examples of models with their names of reduced complexity are given in bold italics.

Dimension		Ocean 0	Ocean 1	Ocean 2	Ocean 3
Atmosphere	0	global EBM *Saltzman Models* pulse response models	global mixing models geochemical box models advection-diffusion models, ***HILDA***	thermohaline models (lat/z): wind-driven circulation models (lat/long) deep ocean models (lat/long)	OGCM
Atmosphere	1	EBM (lat) radiative-convective models (z)	–	ocean (lat/z) + EBM (lat) ***BERN2.5D***	–
Atmosphere	2	EBM (lat/long)	statistical dynamical atmosphere + diffusive ocean, ***MIT 2D***	ocean (lat/z) + statistical dynamical atmosphere (lat/long), ***CLIMBER2*** ocean (lat/z) + stat. dyn. atm. (lat/z), ***MOBIDIC***	OCGM + EBM (lat/long) ***UVIC*** OCGM + QG atm. ***ECBILT***
Atmosphere	3	AGCM + SST	ACGM + mixed layer	ACGM + slab ocean	**A/OGCM**

A fourth approach, which complements the model hierarchy, is to build substitute models. More complex models are represented by either linearizing them by so-called *pulse-response models*, or by constructing substitutes based on sophisticated approximation methods. A recent promising avenue is to employ *neural networks* and train these networks with results from climate models (Knutti et al., 2003). For example, the neural network representation of the BERN2.5D model is several orders of magnitude more efficient than the original model, once training of the neural network is completed (Fig. 1). This opens unexplored possibilities with such climate model substitutes. In the future, climate models not only need to provide reliable projections of climate change, but they are also expected to yield quantitative estimates of uncertainties. Ways how to calculate such uncertainties, and how to constrain them with available observations have been demonstrated in the framework of reduced complexity models. Rather than giving final predictions, these simplified models thus exhibit their skill by serving the community to explore new methodologies at comparatively low cost. The lessons learned can then be applied to comprehensive, state-of-the-art climate models.

Simplified models also give access to long time scales extending over many 10,000s of years. To investigate climate changes on these time scales, large ice sheets must be included in such models. Efficient models of intermediate complexity have filled this gap which is currently inaccessible for comprehensive models, and have provided insight into the possible ocean-ice sheet feedbacks involved in abrupt climate change (Calov et al., 2002; Schmittner et al., 2002).

The limited degrees of freedom in simplified models is responsible for the fact that they often underestimate natural variability. This may lead to a general bias towards deterministic interpretations in explaining mechanisms of climate change. Some recent studies with reduced complexity models including both atmospheric and oceanic variability suggest that natural variability could have played an important role in, e.g., the occurrence and duration of abrupt climate events (Renssen et al., 2001; Goosse et al., 2002).

Reduced complexity models have also become increasingly important as "integrators" in climate research (Alverson et al., 2003). Records of past climate changes obtained from different paleoclimatic archives and different geographic locations are often difficult to synthesize. But simplified coupled physical-biogeochemical climate models can provide crucial help in integrating diverse pieces of information which otherwise could not be interpreted. This is particularly evident in cases where information about biogeochemical cycles needs to be

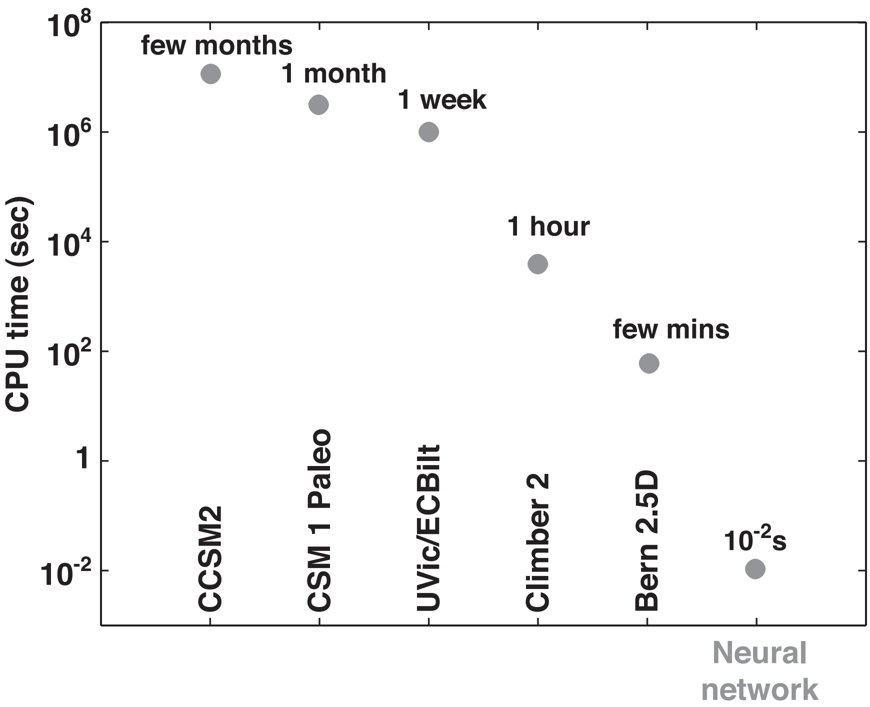

Fig. 1: Comparison of very approximate estimates of CPU requirements of a typical global warming simulation of 250 years for a hierarchy of climate models. (Knutti et al.*, 2003).*

combined with dynamical aspects of climate change. Whereas until recently, the geochemical community routinely relied on box models, simplified dynamical models have now matured to the stage where they can be used to investigate problems related to physical-biogeochemical interactions in the climate system. For example, the potential and limitation of new paleoceanographic tracers has been assessed by such models (Marchal et al., 2000). The inclusion of simplified formulations of the terrestrial vegetation cover permits the investigation of new feedback mechanisms in the climate system that might be crucially important to understand past and future climate change (Brovkin et al., 1999; Claussen et al., 1999).

Before wide-ranging conclusions are drawn based on simplified models, however, it is important that consistency with dynamically more complete models be checked. One recent example concerns the role of the high latitude oceans in determining changes in the atmospheric CO_2 concentration. A thorough comparison of the effects in the carbon cycle model hierarchy ranging from box models to comprehensive OGCMs revealed that the simplified representation of mixing in the high latitudes employed by box models resulted in an overestimation of the link between meridional overturning in the Atlantic and atmospheric CO_2 concentration (Archer et al., 2003). Two-dimensional models of intermediate complexity, on the other hand, showed a behaviour that was consistent with that of the comprehensive OGCMs. This demonstrated that for this particular application, the reduced complexity models already contained sufficient detail to provide a consistent answer. It is obvious that such agreement cannot be taken as a general license, but that consistency with more comprehensive models and/or observations must be checked, where possible, for each application.

The increasing importance of climate models that occupy the intermediate realm of the model hierarchy has also been highlighted by the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2001) which contained a subsection on this type of models and presented results from long-term simulations on the evolution of sea level rise, carbon uptake and other slowly adjusting quantities in the climate system. While the standard IPCC scenario calculations have traditionally been performed with box models, models of intermediate complexity are now ready to be used for extensive calculations necessary for upcoming assessment and technical reports under the auspices of IPCC.

Apart from paleoclimate modelling, where models of reduced complexity have already been applied successfully to study processes on long timescales of thousands to millions of years, efficient climate models could probably be used more extensively in the field of Integrated Assessment (Nordhaus, 2001). Contributing to assessment efforts such as IPCC, economic models and climate models are often used separately and sequentially by first developing a scenario of the future (in terms of population, economy, energy demands, etc.), calculating climate change for a given fixed scenario, and finally estimating impacts, costs or benefits in a third step. However, interactions between political decisions and climate change could become important in the future in defining and modifying a scenario. This would impact mitigation strategies and optimization of emissions paths for future development at minimal damage or energy cost. Such efficient coupled climate-economy models could contribute to close the gap between scientists, politicians and economists. This would represent a quantum leap in designing new strategies for coping with future climate change.

While simplified models occupy an important place in climate dynamics, their developers and users bear a special responsibility. It is only through extensive parameter exploration and ensemble simulations that these models provide added value in climate studies. If used judiciously, they serve as "hypothesis generators" and actually represent useful precursors to subsequent targeted simulations with more complete climate models.

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Status and goals of global data syntheses

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Introduction

This paper is a summary of a review paper by Stammer et al. (2003c) (henceforth referred to as SEA03) that accompanied a talk on the subject of the global WOCE synthesis that was given at the Final WOCE Conference in San Antonio, November, 2002. As is described in detail by those authors, substantial progress has been achieved internationally over the last years regarding the availability of a global dynamically self-consistent WOCE Synthesis. The ocean (in situ and satellite) data-base and modeling and computing capacity have advanced to the point where true four dimensional estimates of the global time-evolving general circulation are practical in a routine and sustained way. To a large extent, this statement is a vindication of the vision that such estimates could become possible during WOCE and that they would form the basis for further advancements of oceanographic and climate science. The capabilities of global ocean state estimation are available as a legacy from WOCE. They now need to be sustained and improved as a backbone of CLIVAR's regional and global climate research.

As opposed to numerical simulations, ocean state estimation is mathematically an inverse problem (often referred to as data assimilation). It combines diverse and relatively sparse observations with a state-of-the-art ocean general circulation model (GCM) to obtain a dynamically self-consistent solution of the ocean circulation and (in principle) its uncertainties. Results are intended to be used to estimate observable and unobservable quantities of the ocean, to understand uncertain model parameters such as mixing, to provide initial conditions for coupled climate prediction systems, or to help design a cost-efficient climate observing system, among many other applications.

Thorough treatments of assimilation approaches can be found in the text books by Bennett (1992) and Wunsch (1996) and recent applications are summarized in Malanotte-Rizzoli (1996) and in Fukumori (2001). Many of the so-called 'advanced' assimilation methods originate in estimation and control theories (e.g., Bryson and Ho, 1975), which in turn are based on 'classic' inverse methods. These include the adjoint, representer, Kalman filter and related smoothers, and Green's function methods. All those techniques are characterized by their explicit assumptions under which the inverse problem is solved consistently. Many simpler approaches exist as well that make it computationally easy to obtain an apparent solution to a data assimilation problem. These include optimal interpolation, "3Dvar", 'direct insertion", "feature models", and "nudging". They originate mostly from atmospheric weather forecasting and are largely motivated in making practical forecasts by sequentially modifying model fields with observations. However, they usually do not account for model and data uncertainties, and observations that formally lie in the future are generally not used in the estimate.

The fundamental importance of a physically consistent state evolution for climate research and the intricate relation between the fully time-dependent estimated state and control variables such as surface forcing is usually ignored by simple approaches. Only advanced, i.e., physically self-consistent, estimates of the evolution of the ocean state can lead to new insights regarding mechanisms and processes that govern the ocean and determine its role in climate.

How far have we come?

Recent advances in state estimation are fundamentally associated with recent infrastructure developments and advances that include model developments (Griffies et al., 2001; Marshall et al., 1997; Marotzke et al., 1999), the development of adjoint model compilers (e.g., Giering and Kaminsky, 1998), the development of model-data interfaces and the expansion of computational resources. However, to reach the goal of global ocean syntheses, additional innovations in estimation theory were required which included check-pointing and re-computations in adjoint models and divided Kalman Filter-Smoother approaches. Combined with improvements in computational capabilities, those innovations have finally enabled ongoing applications of optimal estimation methods feasible for many data assimilation problems on global scale. See Marotzke et al. (1999) and Fukumori et al. (1999) for more details.

Several attempts are now underway that routinely estimate the time-evolving ocean state for up to a decade from basin to global scale. Data used in the estimation procedure include the entire suit of observations available from WOCE and the observing system in the ocean. Data assimilation will evolve further over the next decade as part of CLIVAR. However, results have reached the point where the community has started to use them on a routine basis for quantitative studies. Many diverse and overlapping applications are explained in detail by SEA03. Ongoing estimation efforts benefited significantly from efforts like the Live Access Server (LAS) which they use as interfaces to provide their results to the wider community through project-related data and model servers (see http://ferret.wrc.noaa.gov/Ferret/LAS/LAS_servers.html for an extended list of existing servers).

To demonstrate the progress made in our understanding of the ocean through state estimation over the last several years, one would need to discuss many aspects of the general circulation, including the flow field, ocean transports of heat, freshwater and volume, regional budgets of heat and freshwater, surface fluxes and vorticity and bottom torques. Limited space allows mention of only a few aspects here.

An example of a state-of-the-art estimation is shown schematically in Fig. 1 (page 18) which lists the data used by the ECCO consortium (Stammer et al., 2002a, b) to constrain the ECCO global adjoint model. Also shown are the control variables (e.g., initial conditions, the time-varying surface forcing or model mixing parameters), which are estimated in a way that brings the model into a best-possible consistency with the WOCE data.

Fig. 2 compares the net meridional heat transport from the ECCO 1° global WOCE synthesis with recent results from Ganachaud and Wunsch (2000). The model results show significant detail in the meridional heat transport. At some latitudes they are consistent with the results from static box inversions, but not everywhere and it remains to be investigated what the impact of temporal variability on those estimates are.

Because state estimation produces surface flux fields that bring the model into consistency with ocean data, the procedure provides insight into uncertainties of surface forcing fields and possibly uncertainties in atmospheric models by using information embedded in ocean observations. Fig. 3 (page 19) shows the estimated net surface heat flux together with the estimated time-mean changes relative to the NCEP first guess fields that are required to bring the model into consistency with observations. While adjustments are generally consistent with our understanding of NCEP net heat flux errors, they appear somewhat large over boundary currents that are not fully resolved in the state estimate.

To provide an example of climate relevant results that emerge from the state estimation, Fig. 4 (page 19) shows the net heat uptake of the model which essentially agrees with Levitus et al. (2001) results and is associated with a 2 W/m^2 net heat uptake over the model domain. With the results from the state estimation we can now start to study the associated spatial pattern and their relation to changes in surface forcing fields.

How far might we get?

Today we are in a phase where physical oceanography and climate research are rapidly migrating towards more operational applications of ocean state estimation. Those efforts will allow us to estimate changes in the ocean circulation on seasonal to longer climate relevant time scales, similar to re-analysis projects in the atmospheric community and will be the backbone of global and regional CLIVAR research activities. An expression of this fact can be found in many CLIVAR documents that firmly plan CLIVAR observing and analysis activities around ocean state estimation components.

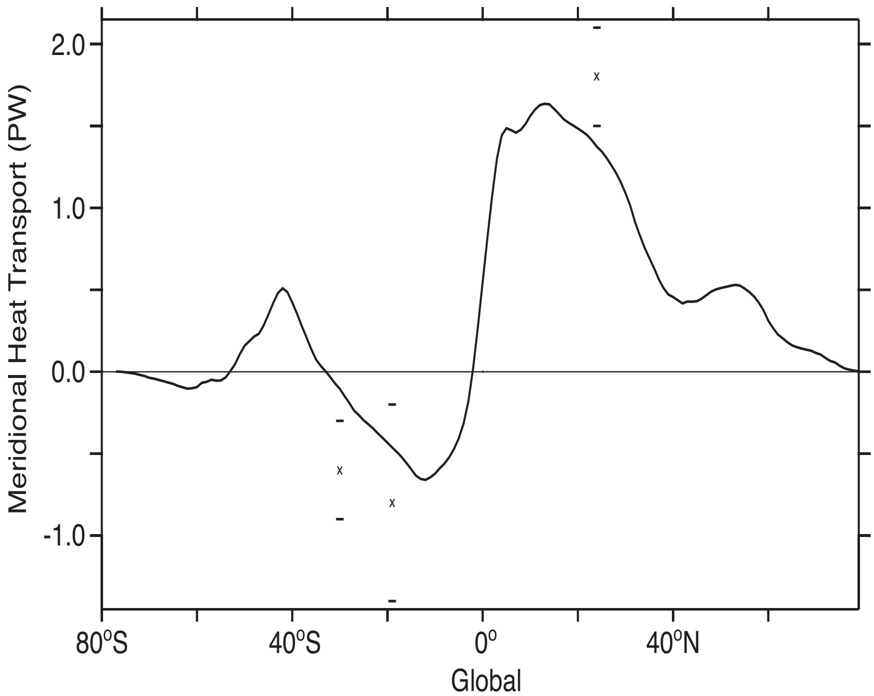

Fig. 2: Time-mean meridional heat transport, zonally integrated as they results from the 1° ECCO WOCE synthesis over the entire ocean. Also shown are Ganachaud and Wunsch results from a box inversion and their error bars. See Köhl et al. (2003) for details.

What developments are required to reach the level of operation and quality required to support climate research and its applications? Several requirements come into mind: (1) Improving prior process and error statistics; (2) improving model physics and increasing the model resolution; (3) extending the control space to include model error terms; (4) extending the estimation period to cover climate-relevant decadal time scales. Beyond those immediate issues, we have to worry about more practical questions, such as: what data are required (i.e., which variables do we need most urgently in state estimation) and where should they be measured?

To produce the best possible estimates of the changing ocean and its relation to atmospheric forcing and internal mixing, long ocean synthesis efforts are now underway that intend to produce rigorous ocean estimates for the last 50 years, in parallel to NCEP and ECMWF reanalysis activities. It can be expected that those results will provide the basis for understanding decadal variability in the ocean, understanding errors and changes in surface flux fields, and will provide detailed information about mixing and water mass formation in the ocean.

A long-term goal is to use the ocean state estimates not only to study climate variations during the last decades, but to properly initialize coupled climate models. Related activities are now being launched in the context of using ocean syntheses for seasonal forecasts (Galanti et al., 2003; Dommenget and Stammer, 2003) and in anthropogenic climate change studies (Pierce et al., 2003). Ultimately, this will require us to constrain not just ocean models but the coupled system as a whole, and to use the dynamically balanced solution for climate studies. However, constraining coupled systems requires a significant improvement in our knowledge about biases in coupled ocean models and their implications for balanced estimates. The most notorious problem encountered in today's AGCMs, from the ocean modeler's perspective, is their inability to control the escape of water vapour from the atmospheric boundary layer. This makes it very hard to form and maintain stratus clouds. The absence of low-level marine stratus in AGCM simulations today is the biggest source of SST errors in coupled simulations.

The ultimate success of state estimation depends on many issues. But ready availability of observations is an obvious requirement. In light of the extent of the WOCE observational data set, such processing, including data assemblage amenable for model integration, is a nontrivial task. It requires careful planning of CLIVAR with respect to maintaining high-quality in situ and satellite data streams, archiving and handling those global observations and preparing them in a way that they are useful for global ocean syntheses.

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Routine ECCO[1] ocean syntheses available through the internet

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The ECCO Consortium uses rigorous global ocean state estimation methods to produce dynamically consistent time-varying model/data syntheses over the 10+ year period from 1992 to present as the basis for studies of a variety of scientific problems. Rigorous estimation methods are computationally demanding. However, they are essential in obtaining dynamically self-consistent estimates useful for understanding the physics of the time-evolving ocean and its interaction with the atmosphere by exploiting the information contained in ocean and satellite data.

ECCO estimates are based on the MIT general circulation model (Marshall et al., 1997), which employs advanced mixed layer physics and an eddy parameterization scheme. Ongoing efforts of the ECCO Consortium are producing two sustained near global analysis products: (1) A near-real-time product on a nominal 1° horizontal grid telescoping to $1/3^{\circ}$ toward the equator with 46 levels assimilating altimetric sea surface height and in situ temperature profiles using a Kalman filter-smoother, (2) A product assimilating all available data on a 1° horizontal grid with 20 levels using an adjoint model. Both estimates are forced by daily heat and freshwater fluxes and twice-daily wind stress fields.

The results from those two products are available to the public and are distributed through the internet. They can be accessed via the consortium's data server (Live Access Server at http://www.ecco-group.org/las). Model output comprises weekly to monthly averages of the full model state, twice-daily sea surface height and bottom pressure fields, as well as the surface forcing fields that are part of the estimated solution. Other fields or additional diagnostics can be made available upon request. See Lee et al., (2002), and Stammer et al. (2002, 2003a,b) or http://www.ecco-group.org) for details. A release and full documentation of both forward and adjoint ECCO codes is available at http://mitgcm.org/sealion.

ECCO Live Access Server (LAS) http://www.ecco-group.org/las

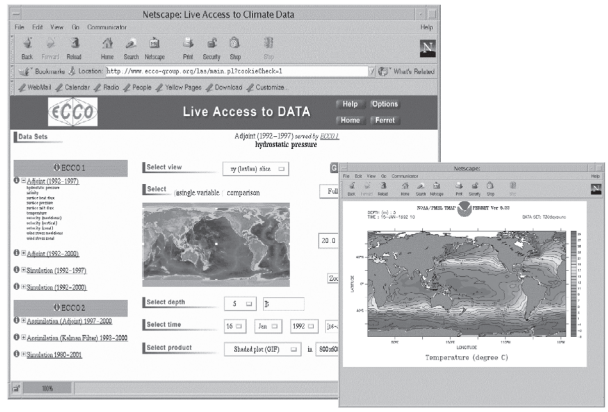

Fig. 1: The ECCO project Life Access Server Interface. The server allows an online view of horizontal maps or vertical sections as well as time series of all model fields. It also allows the plotting of differences between specified period or different model results. The ECCO LAS is linked to the Server of the Global Ocean Data Assimilation Experiment (GODAE) and builds on the infrastructure developed at PMEL (see http://ferret.wrc.noaa.gov/Ferret/LAS/ferret_LAS.html for details).

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[1] The ECCO ("Estimating the Circulation and Climate of the Ocean") project is a consortium between scientist at JPL, MIT and SIO. It is funded under the National Oceanic Partnership Program (NOPP) with funding provided by the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), and the Office of Naval Research (ONR).

Acoustic thermometry in the North Pacific

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1. Introduction

Ocean acoustic tomography (Munk and Wunsch 1979, 1982; Munk et al., 1995) is a multipurpose remote sensing measurement technique that has been employed in a wide variety of physical settings. Basin-wide and regional tomography were accepted as part of the ocean observing system by the OCEANOBS'99 conference (Koblinsky and Smith 2000; Dushaw et al. 2001). In the context of long-term oceanic climate change, acoustic tomography naturally integrates over the mesoscale and other high-wavenumber noise. Tomographic measurements can be made without risk of calibration drift, and they are naturally complementary to other techniques (Dushaw et al., 2001).

Measurements of large-scale temperature by long-range acoustics are now being obtained in the central North Pacific ocean as part of the North Pacific Acoustic Laboratory program (NPAL) and as a continuation of the Acoustic Thermometry of Ocean Climate program (The ATOC Consortium, 1998; Dushaw and Worcester 2001). ATOC began as an ambitious project in the early ,90's, but became embroiled with marine mammal permitting issues. These legal issues prevented acquisition of regular acoustic transmissions until now. The time series described here began in early 1997 as part of ATOC, but was intermittent during 1997-1998 and halted after that because of permitting issues. The acoustic travel time data obtained by long-range acoustic transmissions from an acoustic source near California (the Pioneer source, since removed in accord with permitting protocols), and the inversion of those data to obtain a measurement of temperature, have been described by Dushaw et al. (1999), Dushaw (1999), and Worcester et al. (1999).

In January 2002, the acoustic transmissions resumed using a single acoustic source located north of Kauai and several receivers scattered over the North Pacific basin (Fig. 1). The travel times to the distant receivers of the acoustic signals along identified ray paths are a measure of temperature averaged over the ocean section sampled by those ray paths. Regular acoustic transmissions are to be made on every fourth day, and 6 transmissions are made on that day. The travel time data on each day are averaged to reduce the noise caused by internal waves, tides, etc.; this is the only filtering that has been applied to the time series. The time series described here may be viewed at http://faculty.washington.edu/dushaw/atoc/. It is our intention to update these time series roughly monthly as new data are acquired, and we will make these data available on a request basis.

2. Acoustic thermometry and the JPL ECCO model

Data assimilation has always been an central aspect of the line-integrating tomography data, and global ocean models have only recently become realistic enough to be able to model and assimilate this data type. The analysis of path integral data is made simpler by ocean state estimation methods, using travel times as integral constraints on the model variability. If the data estimated by the model do not match the observations, then the ocean model state is adjusted to bring the model into better agreement. In the case of the acoustics, the different ray paths have different sensitivities to the surface and to the deep ocean, and the estimation can exploit this to obtain vertical information from a set of rays. State estimation by data assimilation also serves to best combine disparate data types, and those data types can then be evaluated for their relative contributions to reducing the uncertainty of the model solution. In addition to the obvious measurement of large-scale heat content over the next few years, one goal of this project is to use the data assimilation to test the degree of complementarity of the acoustic and float (ARGO, 1998) data types. It is not obvious that these two data types are redundant as some have suggested. The ECCO consortium (Estimating the Circulation and Climate of the Ocean; Stammer and Chassignet, 2000, Stammer et al., 2001), including groups from the Jet Propulsion Laboratory (JPL), the Massachussetts Institute of Technology,

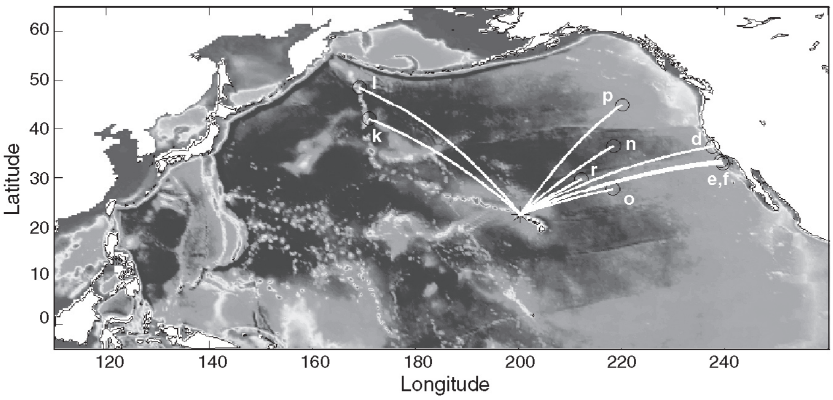

Fig. 1: The paths from the Kauai acoustic source to various SOSUS (Sound Underwater Surveillance System) receivers in the North Pacific for which resolved ray arrivals have been obtained. An acoustic source that was deployed near California (the Pioneer source, near site d in the figure) was removed in 1999 in accordance with permitting protocols.

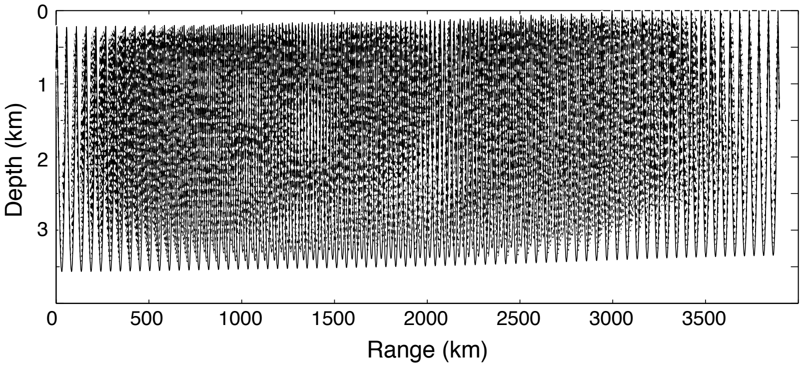

Fig. 2: Ray paths associated with the resolved ray arrivals for the acoustic path from the Kauai source to receiver d near California. Where the path travels through warm tropical waters near Hawaii, the rays do not sample to the ocean's surface.

(MIT) and the Scripps Institution of Oceanography, is proceeding to incorporate the acoustic data type in its global ocean models (Stammer, 2002, personal communication).

A preliminary description of the results of assimilation of the thermometry data into an ocean model (The ATOC Consortium, 1998) had considerable uncertainty in the conversion of the sub-surface temperature measurements into a measurement of sea-surface height for comparison to the TOPEX/POSEIDON data. As a result, sea-surface height variations estimated from the acoustics were about half as large as those measured by altimetry. This issue was at the root of the exchange of Kelly et al. (1999), and the reply by the ATOC consortium; acoustic thermometry is not a measure of sea-surface height. Fig. 3 shows the comparison of some of the data used in the 1998 paper (Pioneer to receiver k) with the ECCO model predictions. The primary result of the 1998 paper was to show that all the pieces were in place to bring the acoustic data into global ocean models by data assimilation.

The ocean state estimate used here is implemented by the ECCO group at JPL. The estimate is based on integration of the MIT General Circulation Model in a global configuration that spans 75°S to 75°N, with latitudinal grid spacing of 1 degree. The model has 46-levels, 15 of which are within the top 150m at 10m resolution. The model assimilates a variety of satellite and in-situ data and data products, including TOPEX/POSEIDON, WOCE hydrography, XBT sections, etc. A description of this state estimate and the complete fields are available at http://eyre.jpl.nasa.gov/external/.

The data obtained using the Kauai acoustic source are similar to those using the Pioneer source, but interpretation of a time series of temperature that might be derived from the acoustic data is complicated by the ray path sampling. In tropical regions, the ray sampling is not completely to the ocean surface because of the warm near-surface temperatures. To the north of Hawaii, and towards the region of the California Current, the rays become surface reflecting where the near-surface water temperatures are cooler (e.g., Fig. 2). A variable that offers a more appropriate comparison for the acoustics is travel time, the quantity that is actually measured.

As a first step towards incorporating travel times into the ECCO model cost function, ECCO model output was used to calculate travel times for several source-receiver pairs (Fig. 3). The time-mean state of the model proved to have unphysical sound speed characteristics, so it was replaced with that of the 1998 World Ocean Atlas (http://www.nodc.noaa.gov/OC5/readme.html). Technically, this required correction may be viewed as a first adjustment to the ocean model required by the acoustics. The amplitude of the annual cycle in travel time for an acoustic path from Pioneer to receiver k compares quite well with the ECCO model, although the model appears to have an unphysical trend in temperature. The rays for this path are entirely surface reflecting. Note that the data and the model also show approximately the same change in the dispersal of the ray travel times in response to the seasonal cycle of temperature in the top 70 m or so of the ocean. In the central Pacific, a slight warming over the past five years is observed acoustically (Kauai to receiver k) and also in the model, while in the eastern Pacific cooling is observed acoustically (Kauai to receiver f) and by the model.

Hawaiian waters have significant mesoscale variability (particularly thermal), which is the origin of the O(30-day) variability in the acoustic time series; the mesoscale is not yet resolved by the ECCO model. The mesoscale variability of the California Current has a negligible thermal content.

3. Temperature

For the data obtained by the Kauai acoustic source, most of the comparisons of upper-ocean temperature (e.g., 0-1000 m) derived from the acoustics do not compare well to either TOPEX/POSEIDON or the ECCO model because of the ray path sampling. One path where a reasonable comparision might be made is the path from the Kauai to receiver k (Fig. 4), because on that 4-Mm path the rays become surface reflecting after about 1 Mm as they travel northwestward into subtropical regions. On this path, the acoustical estimates of temperature are similar to equivalent estimates from the ECCO model in terms of the annual cycle and the trend over the 5-year record length. The second example, Kauai to receiver f, shows a similar comparison for a case when the ray sampling is not completely to the surface. In this case, the time series are quite different. The formal uncertainties

continued on page 20

From Roemmich and Gould: The Future of In Situ Climate Observations for the Global Ocean (page 4)

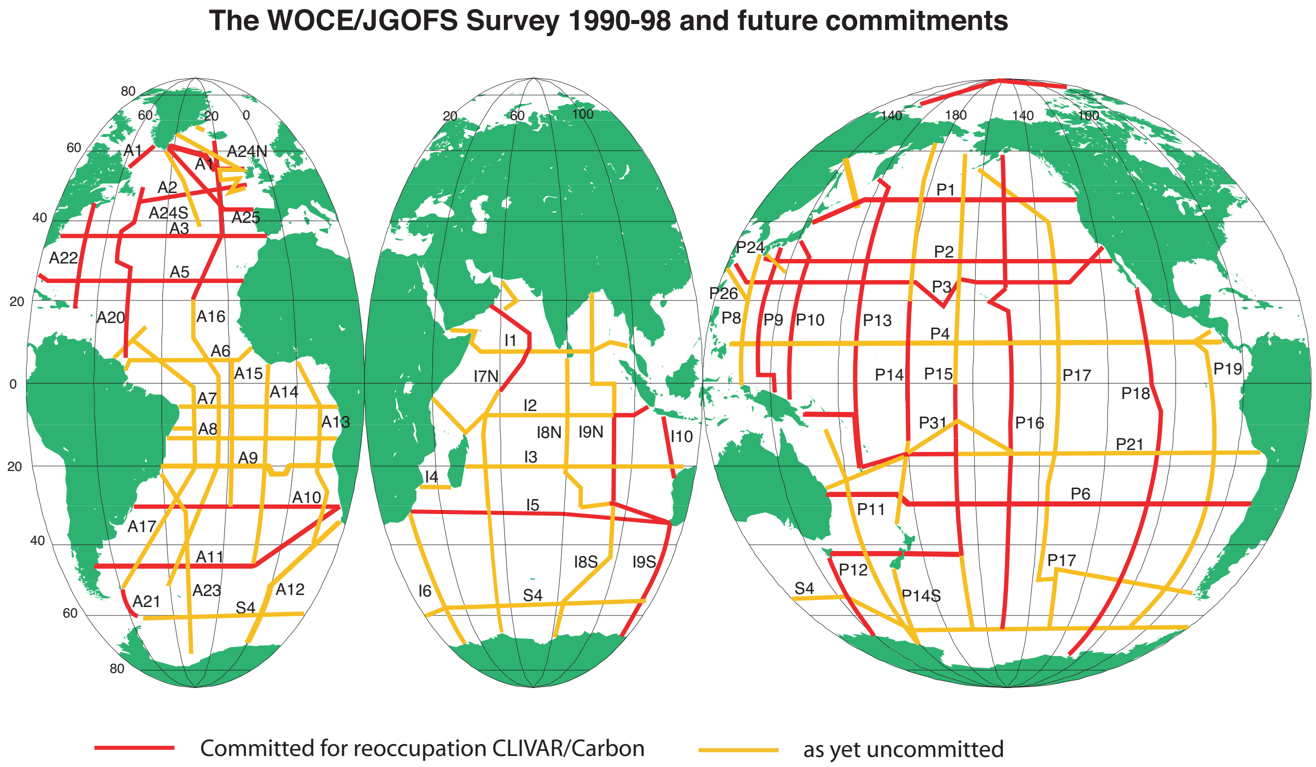

Fig. 2: Implementation status map for CLIVAR/Carbon repeat deep-ocean hydrography. (http://www.clivar.org/carbon_hydro/hydro_table.php)

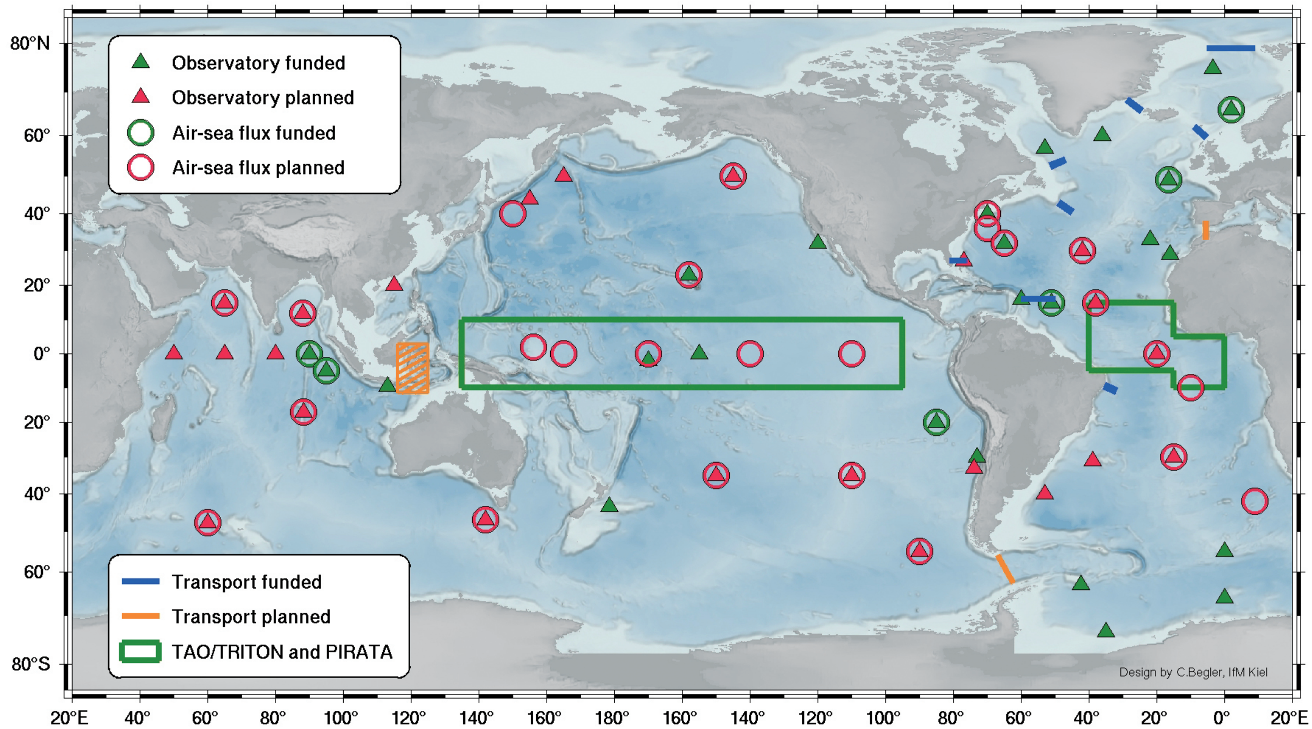

Fig. 3: Implementation status map for ocean time-series stations.

From Roemmich and Gould: The Future of In Situ Climate Observations for the Global Ocean (page 4)

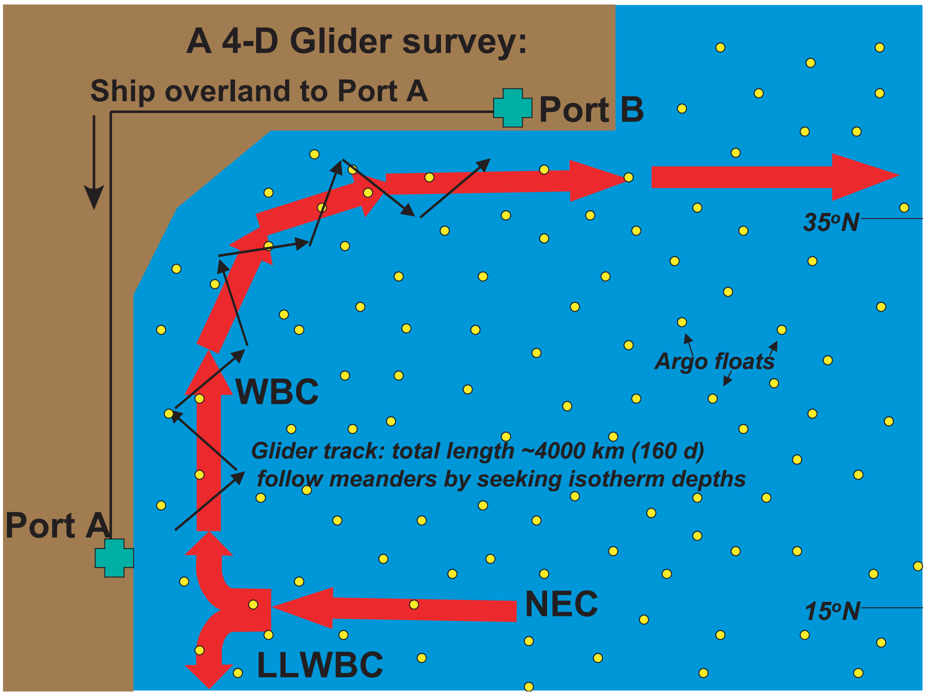

Fig. 4: Schematic diagram of glider sampling plan in a mid-latitude western boundary. Gliders are deployed upstream near Port A. They zigzag across the current downstream to a recovery point near Port B, and are recovered and returned overland.

From Stammer: Status and Goals of Global Data Syntheses (page 11)

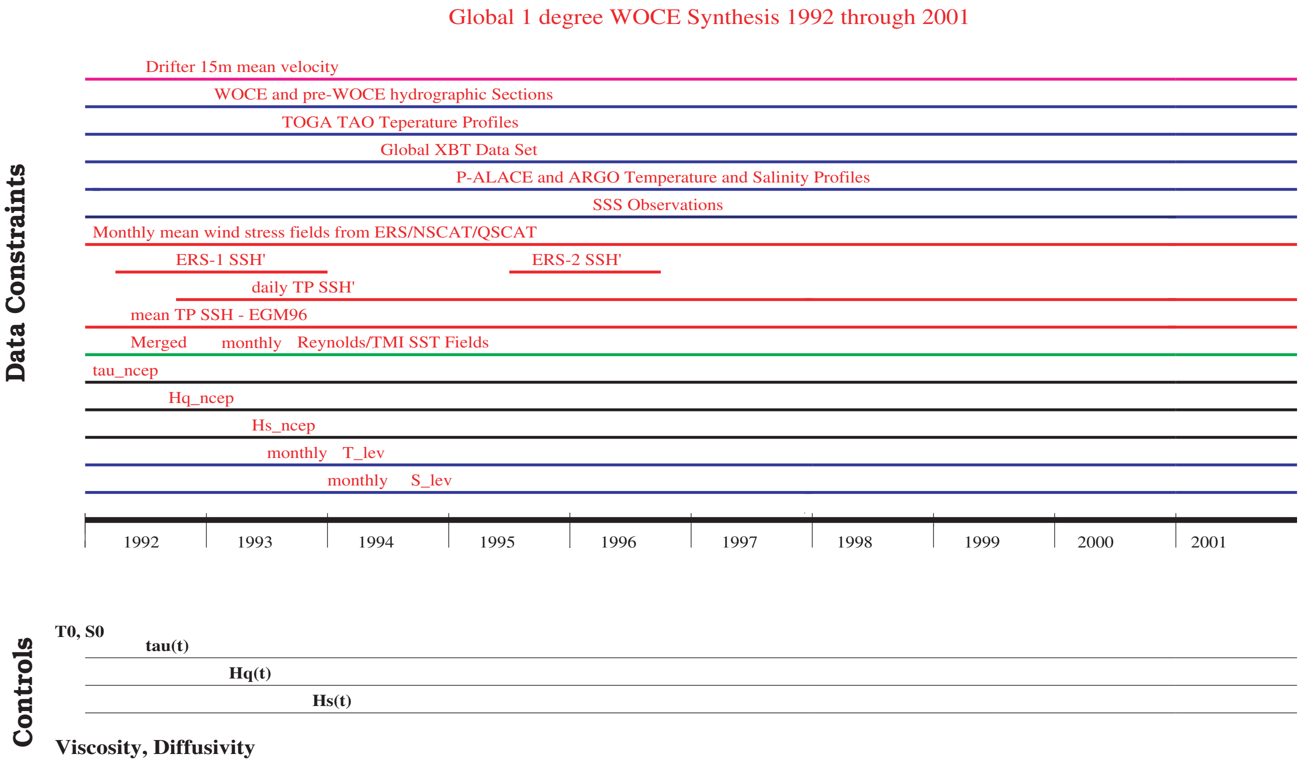

Fig. 1: Schematic of a typical global WOCE synthesis, obtained from the ECCO Consortium on a 1° global grid. The upper part shows the observations used to constrain the model. Control parameters that are adjusted to fit the model to the data are shown in the lower part of the panel. They typically include the initial temperature and salt fields, the time-varying surface forcing and mixing coefficients.

From Stammer: Status and Goals of Global Data Syntheses (page 11)

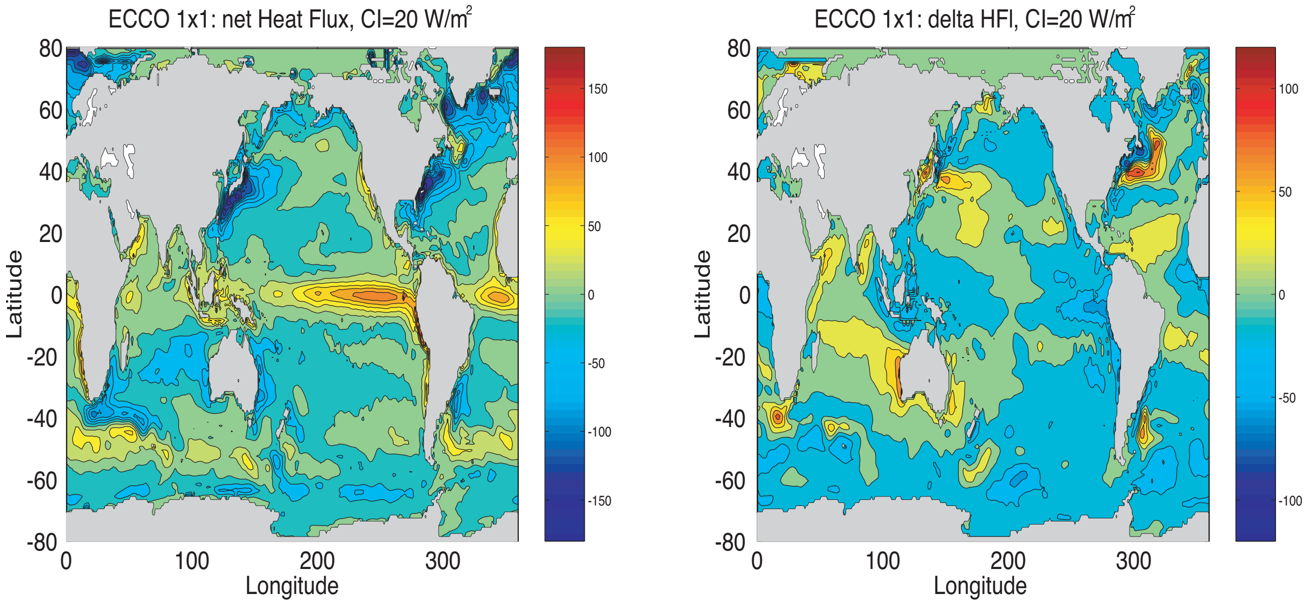

Fig. 3: The mean net surface heat flux field (left) as it results from the ECCO 1° WOCE synthesis over the period 1992 through 2000. Time-mean changes in net surface heat exchange relative to the prior NCEP fields are shown in the right panel (in W/m²). See Stammer et al. (2003b) for details.

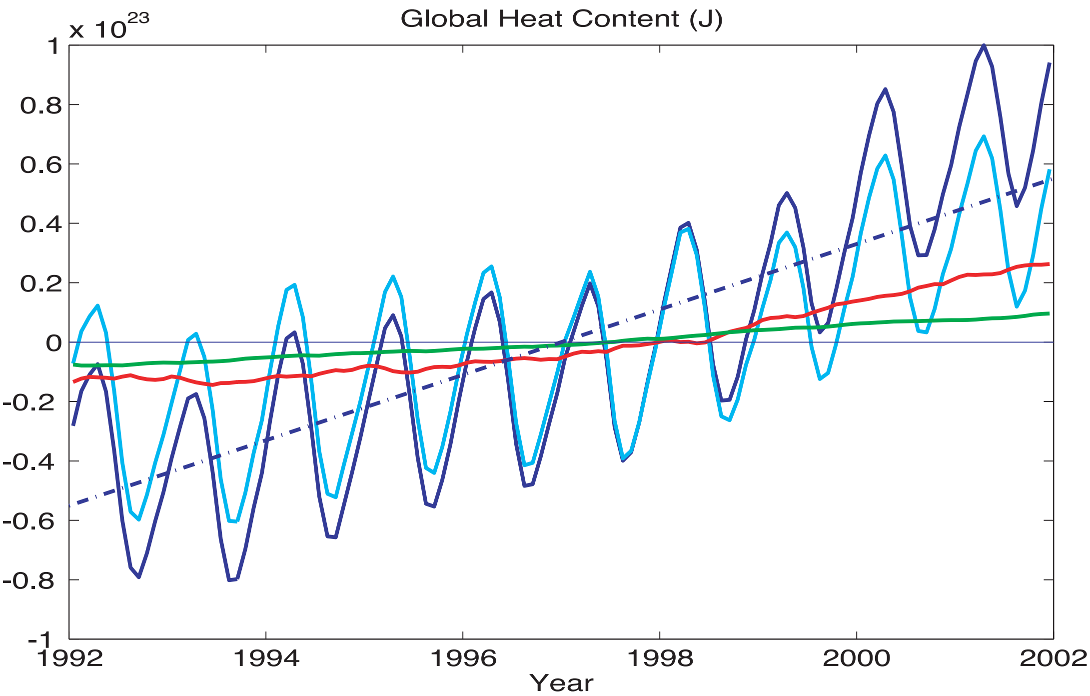

Fig. 4: Time series of the global heat content of the ECCO solution (blue) together with those computed separately over the top 510m (cyan), from 510 to 2200m (red), and from 2200m to the bottom (green). Also shown is in an estimate of global heat content increase obtained from Levitus et al. (2000) (dashed-dotted line). A temporal mean was removed from all curves. The global increase in heat content is about 1.5x10²² J over the 10 year period 1992 through 2001, a number that is close to the estimate provided by Levitus et al. (2001) and corresponds to a global heat uptake of the ocean by about 2 W/m². The top layer contributes about half of this increase, but a significant contribution actually happens also below 2000 m depth. Note also that the increase comes to a halt in the top layer during the last ENSO event. See Stammer et al. (2003a) for details.

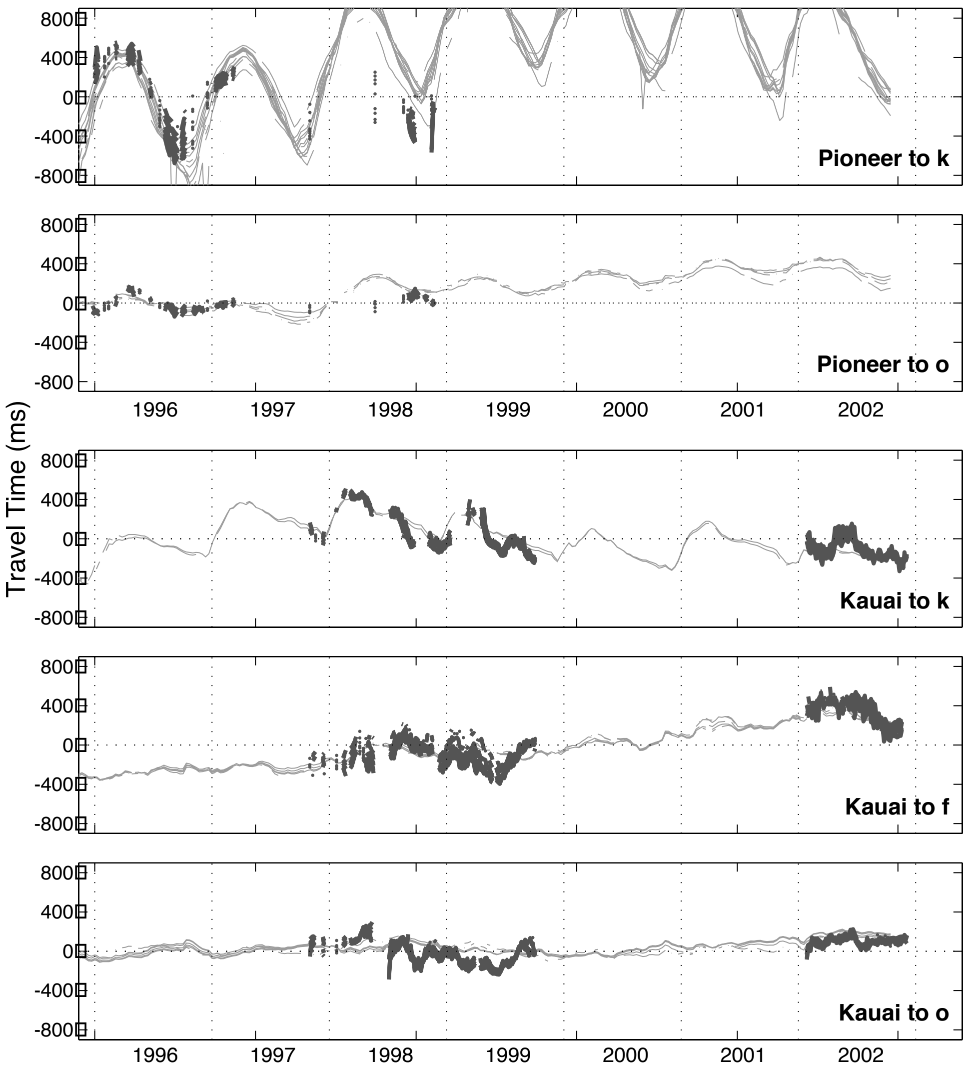

Fig. 3: Travel time variations for the ATOC sources at Pioneer Seamount and Kauai transmitting to receivers k, o, and f (dark lines, see the ATOC map for receiver locations), compared with the travel times calculated from the ECCO state estimates (light lines). Each line represents a different ray path, which samples the ocean in a different way; typically 6-12 ray arrivals are resolved on each path.

are mainly caused by resolution issues, i.e., the lack of sampling by the acoustic ray paths of parts of the upper ocean, rather than by data noise.

Salinity changes have only a mild effect on sound speed (1 ppt salinity roughly corresponds to 1 m/s sound speed, while 1^{o}C temperature roughly corresponds to 4 m/s sound speed), and there is no evidence that realistic mesoscale variability has a significant effect on the ray paths and the linearity of the inversions of the travel time data to derive temperature.

The ECCO model temperatures and those derived from TOPEX/POSEIDON altimetry also significantly disagree in Figure 4, suggesting either that the model has underestimated the temperature, or that sea-surface height includes more contributions to its variations than just simple steric expansion.

4. Discussion

ARGO data are just now becoming available in the North Pacific for comparison to the acoustic time series. This comparison will be an important milestone for this project, since it will determine the extent to which the float and acoustic data are complementary. While it is true that the acoustic approach does not measure salinity and has other limitations, it is also true that the hydrographic or float approach has difficulty measuring large-scale temperature because of the small-scale noise prevalent in the ocean. Two recent examples of observations of large-scale changes in ocean temperatures by hydrography are provided by Levitus et al. (2000) and Gille (2001, 2002). While these measurements and the acoustical measurements of line-average temperature are different things, a comparison of the various numbers involved demonstrates the good signal-to-noise capabilities of the acoustical approach. Levitus examined the temperature variations in the ocean basins over the past 50 years using all available historical hydrographic data. Time series of temperature variations in these ocean basins were obtained by averaging temperature over the entire ocean basins, and then calculating a 5-year running mean of the timeseries. The error bars in 0-1000 m average temperature obtained for the North Pacific were around 0.01^{o}C, comparable to the formal uncertainty in temperature derived acoustically on a single day on a single acoustic path. Gille (2001, 2002) compared tem-

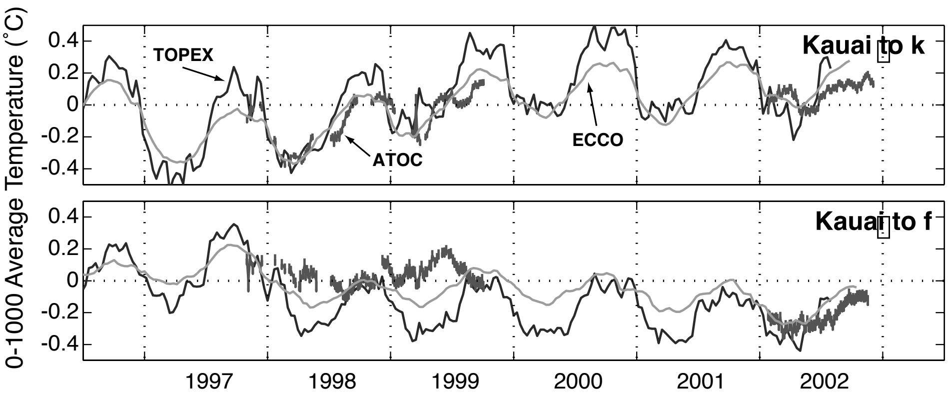

Fig. 4: Time series of temperature, averaged over the range of the indicated acoustic path and over the upper 1000 m, derived from acoustic thermometry, TOPEX/POSEIDON altimetry and the ECCO ocean model. The ray sampling on the path from Kauai to f is not completely to the ocean surface; cf., Fig. 3. To convert the altimetry to a measure of temperature, steric expansion was assumed to occur only in the top 100 m of ocean, and a conversion factor of 48 C/m was used.

peratures observed in the Southern Ocean by ALACE floats parked between 700 and 1100 m depth to climatological temperatures derived using historical hydrographic data. The average temperatures from ALACE floats during the decade of the 1990's were found to be 0.17±0.06°C warmer than the historical temperatures. Over the 5 years that the acoustic data has been obtained, we find (by eye from Fig. 4) that the eastern Pacific between Hawaii and California (path from Kauai to receiver f) has cooled by about 0.2°C, while the central Pacific (path from Kauai to receiver k) has warmed by about 0.2°C, with uncertainties determined mainly by the level of mesoscale variability around Hawaii.

We look forward to seeing how the acoustic timeseries evolve over the next several years, and to a quantitative determination of the relative merits of hydrographic and acoustic data as ocean model constraints.

Acknowledgements

We would like to thank the U.S. Navy for making available the remarkable SOSUS facilities, and for continued co-operation as we use these instruments. We would also like to thank J. Bolstad, L. Buck, D. Reddaway, and J. Wigton at the Applied Physics Laboratory for continuing to acquire and process the acoustic data in a timely manner. The work described in this paper was originally described in a poster (Dushaw et al., 2002) presented at the 2002 "WOCE and Beyond" Conference (San Antonio, TX) with coauthors: B. Cornuelle, B. Howe, D. Menemenlis, J. Mercer, W. Munk, R. Spindel, P. Worcester, and the NPAL Group (http://npal.ucsd.edu/). This work is supported by the Office of Naval Research.

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Variability of western subarctic Pacific boundary currents and coastal sea level

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1. Introduction

During the past decade significant temporal variability has been observed in the western subarctic Pacific, prompting comparison to the regime shift that occurred in the Pacific in 1976-1978, or to the Atlantic's salinity anomaly (Dickson et al., 1988). Our objective here is to discuss variability in the structure of coastal currents, and possible links to the climate system. Our results are based largely on data collected as part of the International North Pacific Ocean Climate Study (INPOC), an intensive CTD survey undertaken to examine the structure and volume transport of the western subarctic currents in the North Pacific.

Two contiguous currents - the Kamchatka Current and Oyashio - comprise the North Pacific's western subarctic boundary current system. The low salinity Kamchatka Current forms at the convergence of the Alaskan Stream and Bering Sea outflow south of Kamchatka Strait and flows southwards along the Kamchatka coast. While the Oyashio is, itself, a continuation of the Kamchatka Current, these two major currents are distinguished by differing forcing dynamics and by two distinct systems of anticyclonic eddies, as revealed by hydrographic CTD data, and by visible and infrared satellite images.

2. Methods and data sources

Detailed CTD observations of the Kamchatka and Oyashio currents were collected during the INPOC project from 1990 to 1996 (Rogachev, 2000). Monthly mean pressure-corrected sea level data at Wakkanai (Hokkaido) and Petropavlovsk (Kamchatka) are obtained from the Integrated Global Ocean Services System (IGOSS) Sea Level Program in the Pacific (ISLP-Pac). ftp://ftp.atmos.washington.edu/pub/jisao/davet/indices;

3. Variability in ocean and atmospheric conditions

3.1 Sea level – Currents associated with inter-basin exchanges are characteristically forced by the wind and by differences in steric sea level between the basins. A well-known example is the sea level difference (40-50 cm) between the North Pacific and Arctic oceans which is thought to drive a mean northward flow through the Bering Strait (cf. Stigebrandt, 1984). Similarly, in the region discussed here, a steric sea level difference between the Pacific subtropical and subpolar gyres results in a sea level difference across the Strait of La Perouse that drives the Soya Warm Current (Takizawa, 1982). To study this mechanism we here use time series measurements of coastal sea elevations measured at tide gauges (adjusted for the atmospheric pressure) in the Sea of Japan (Wakkanai), and Eastern Kamchatka (Petropavlovsk), Figure 1. We suppose that the East Kamchatka station (Petropavlovsk) is representative of subarctic conditions, while the Wakkanai station is representative of subtropical conditions.

Figure 1 shows that the Sea of Japan and East Kamchatka stations are out of phase in their response to seasonal (heat and freshwater) forcing. Off Kamchatka there is a major peak of sea level in December. As a result, sea level difference between the subtropical and subarctic domains (Wakkanai – Petropavlosk) has a strong maximum in summer and clear minimum in December. This difference corresponds to summer enhancement of the northward flux of warm subtropic water, and so the time series of sea level difference between the Wakkanai and Petropavlovsk stations is taken here as a major regional climate index.

Three major features are evident in the long-term times series of amplitudes of seasonal variability at Wakkanai and Petropavlovsk (Figure 1). First, there is positive trend of increased sea level at both Petropavlovsk and Wakkanai (~ 3.1 cm/decade). Second, there are pronounced interannual variations of the seasonal amplitude. Third, the main contribution to interannual variability of the Wakkanai-Petropavlovsk difference is due to sea level variations at the Petropavlovsk station.

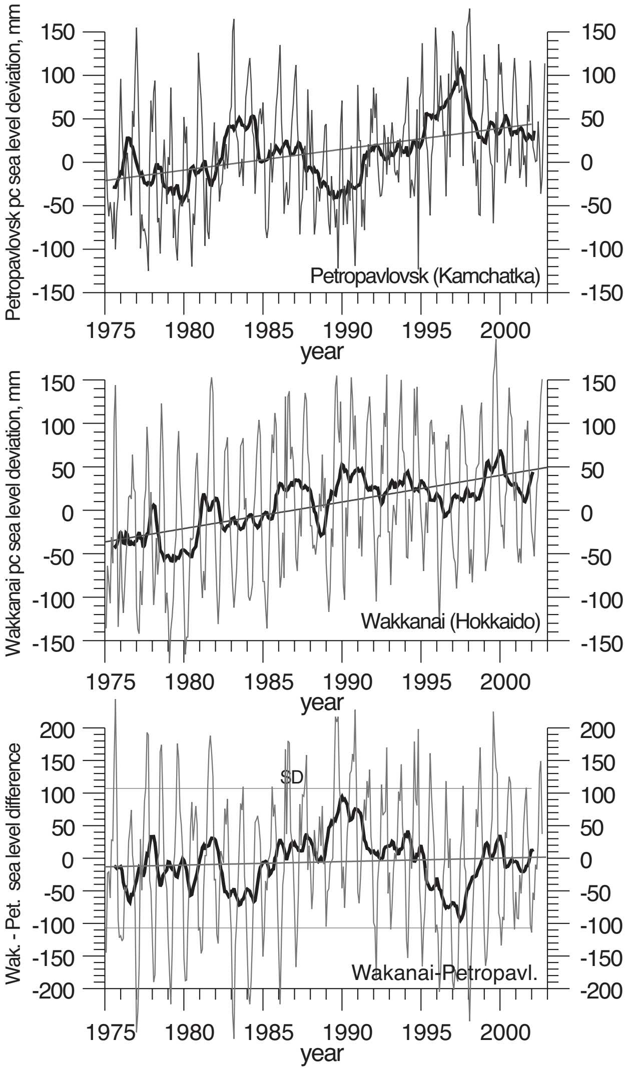

Fig. 1: Long-term variability of pressure corrected sea level at Wakkanai (Hokkaido) and Petropavlovsk (Kamchatka). Note drop of the sea level difference between Wakkanai and Petropavlovsk during thermohaline transition in 1990-1997.

3.2 Western subarctic Pacific coastal currents - The narrow coastal currents, such as Kamchatka and East Sakhalin currents are mainly driven by wind forcing and steric gradients associated with low-salinity water derived from ice melt and river inflow along the coast. The increase of dynamic height near the coast is due to the presence of fresh water transported by the Kamchatka current, and due to deepening of the pycnocline.

We show that sea elevation off Kamchatka is higher in winter as a consequence of the intensity of the southward coastal current originating in the Bering Sea in that season. Now, sea level over the western Bering Sea shelf is related to wind forcing. The along shore velocity v is thus determined by the along shore surface wind stress τ and the bottom stress rv, where r is bottom drag coefficient, or $rv=\tau$. This may be converted into a geostrophic balance, which relates the coastal sea elevation to the Ekman transport.

The coastal flow on the shelf of northern Kamchatka is thus intensified in winter as the sea level slope increases toward the shore. We also note that atmospheric conditions over the western Bering Sea display anomalous behaviour in 1996-1997; the anomalous large southward flux of cold air was associated with higher pressure in the western Bering Sea.

There is evidence that the flow from the Pacific Ocean into the Bering Sea was reduced in 1990-1991 (Reed and Stabeno, 1993). We speculate that large-scale variations in sea level difference may correlate with the Arctic Oscillation index and associated transports of sea ice and low salinity waters by the Kamchatka Current.

4. Summary

The time variability of coastal sea elevations in the western subarctic Pacific are addressed using data spanning several decades. Coastal sea level stations were considered together with available hydrographic stations sampled to 1000 m depth during the INPOC and WOCE projects in 1990-1996. The trends in sea level increase are 2.8-3.4 cm/decade. Strong interannual variability (~ 50 cm) in the sea level difference between stations off East Kamchatka and the Sea of Japan off Hokkaido are noted. Significant seasonal sea level fluctuations (with the range of ~ 50 cm) are due (1) to wind forcing and (2) to steric height change (e.g. temperature and salinity variations). Coincident with changes in coastal sea level, CTD observations from the western subarctic boundary current region of the subarctic Pacific reveal large variability in the dynamic topography of the Oyashio and its mesoscale eddies. Variability in the western boundary current domain is also accompanied by concurrent trends in other climatological indicators, the duration of winter on the continent (period with sub-zero temperatures), and the Arctic Oscillation index.

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Vema Channel: Antarctic bottom water temperatures continue to rise

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The Vema Channel - a choke point for abyssal circulation

During the World Ocean Circulation Experiment (WOCE) significant progress has been made in observing abyssal variability of the South Atlantic. One core project of WOCE, called the Deep Basin Experiment focused on key passages that control the equatorward interbasin exchange of Antarctic Bottom Water (AABW). A commonly accepted definition of AABW describes this water mass as colder than 2°C potential temperature. Particular attention was paid to the zonally aligned Rio Grand Rise separating the Argentine basin in the south from the Brazil basin in the north. Two meridional gaps intersect the Rise at 39 and ~28°W: The Vema and the Hunter Channels (see insert in Fig.1). Repeat hydrography of the 1990s and current meter arrays conducted in the Channels unambiguously reconfirm the pronounced role of the Vema Channel for the transport of AABW with respect to the Hunter Channel in the east and the Santos Plateau towards the west. Based on moored current meter observations in combination with geostrophic velocity computations from hydrographic stations Hogg et al. (1999) reported a total AABW transport across the Ridge of $6.9{\cdot}10^6\,m^3s^{-1}$. On the average 58 % of this volume passes the Vema Channel. The remainder flows through the Hunter Channel. Earlier estimates by Speer and Zenk (1993) inferred from hydrography alone yielded a northward net flow of $6.6{\cdot}10^6\,m^3s^{-1}$ distributed at a ratio of 30 : 59 : 11 on the western boundary current system, and the Vema and Hunter Channels.

After the completion of WOCE further surveys mainly concentrated on the Vema Channel. Investigators from many countries including Germany and Russia are involved. The motivation for revisits of the site in this post-WOCE phase is maintained by a suspicious warming trend in the AABW at the Vema Sill that was first noted by Zenk and Hogg (1996). By today the slowly growing time series of the coldest water in the Vema sill (Zenk et al., 1993) have become CLIVAR research topics of the national programmes in Germany (*"marin-2"*) and Russia (*"Meridian"* programme). It is the purpose of this note to inform the CLIVAR community about present and future mooring works at the Vema Channel. We further report on a continued upward trend of the AABW temperature and its potential cause. The lasting temperature increase was recently observed at this remarkable location of the global abyssal circulation in November 2002.

Recent and planned activities in CLIVAR

Beyond WOCE the *Institut für Meereskunde* (IfM) in Kiel collected more current meter and thermal data from the Vema Sill between 1998-1999 (Tab. 1). To our surprise no significant increase of the moored bottom temperatures could be recognized. Results from current meter and thermistor chain series are in preparation for publication elsewhere. In November 2002 R/V Akademik Ioffe visited both Channels in the Rio Grande Rise again. Both passages -Vema and Hunter - were equipped once more at their choking sills with current meter moorings featuring two instruments at each of the two sites.

Beginning in December 2003 IfM plans to continue the present Russian mooring series in the Vema Channel. RRS Discovery will install an array of moored CTD sensors and current meters concentrating on the AABW level and take additional deep CTD casts across the sill.

On going warming of bottom water

The deployment and recovery cruises of FS Meteor and R/V Akademik Ioffe (expected recovery in November 2003) extended the available data base by a few CTD stations dedicated to the Vema Channel. The 1998/99 Meteor data were already included in Hogg's diagram (Hogg. 2001) summarizing the thermal development of Weddell Sea Deep Water, i. e. the densest admixture of AABW, over almost twenty years. Here we offer the latest data point (cross) in the time series of potential temperature (Fig. 1).

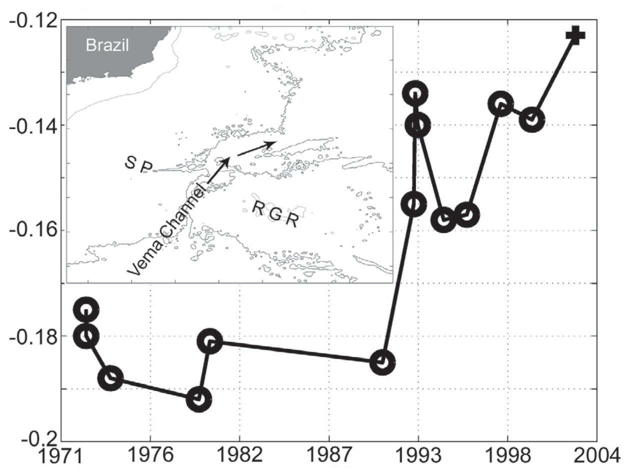

Fig. 1: Observational site (insert) and updated potential temperature (°C) time series of the coldest Weddell Sea Deep Water found in the near-bottom jet on the eastern side of the Vema Channel. The latest CTD data point (cross) was obtained in November 2002. Abbreviations: SP- Santos Plateau, RGR-Rio Grande Rise.

Tab. 1: Post-WOCE mooring activities in the Vema Channel by Germany and Russia with instrumentation in the AABW range. Abbreviations: a.b. –above bottom, CM –current meter, CTD –conductivity-temperature-depth recorder, ThCh –thermistor chain.

Mooring	Latitude °S	Longitude °W	Depth M	Deployment	Recovery
V389					
2 CM, 1 CTD				METEOR 41	METEOR 46
50, 270 and 48 m a.b.	39.333	31.238	4580	21-04-1998	08-03-1999
2 ThCh					
67-267, 290-490 a.b.					
2 CM				AKADEMIK IOFFE	
30 and 50 m a.b.	39.333	31.233	4580	09-11-2002	Nov2003 (planned)
CM and CTD now under discussion	as Kiel *V389*			DISCOVERY (Dec2003)	POLARSTERN (2005)

Ten years after the discovery of the upward shift in potential temperature in the Vema Channel R/V AKADEMIK IOFFE found values of - 0.123 °C on November 9, 2002.

We attribute the increase in the potential temperature record to global warming, which is observed in the 20th century. New et al. (2000) demonstrate that combined land-sea-air temperatures in the Southern Hemisphere have risen more than by 0.5 °C since 1925. Six year long moored temperature measurements by Fahrbach et al. (1998) at the bottom of the central Weddell Sea show a systematic potential temperature rise by ~0.05°C between 1990 - 1995. In the context of the Weddell Polynya of the mid 1970s Robertson et al. (2002) found a subsequent warming trend in the deep waters of the Weddell gyre at a rate of ~(0.012±0.007) °C from 1970 – 1990.

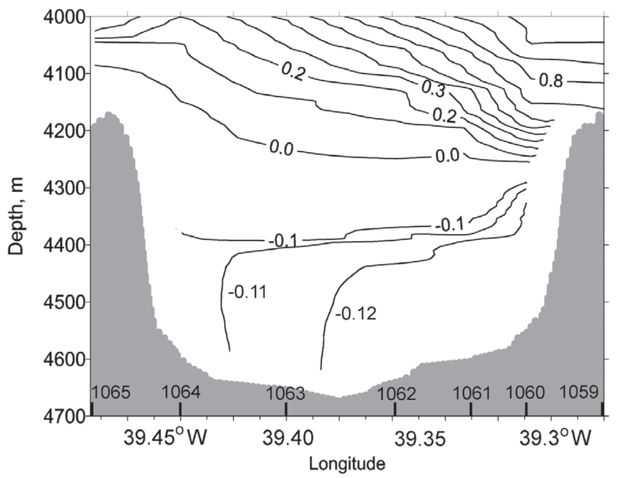

Fig. 2: Potential temperature (°C) section across the Vema Sill (Zenk et al., 1993). CTD stations were occupied by R/V AKADEMIK IOFFE in early November 2002. Note the width of the cold tongue of Weddell Sea Deep Water with Θ < -0.12. During previous surveys this imprint of the coldest WSDW jet was more confined to the eastern flank of the Vema Channel. 1059-1062 are numbers of CTD stations (Shirshov Institute of Oceanology, 2002).

Temperature increase in the Vema Channel may be a remote response to temperature increase in the Antarctic region with a decadal time shift needed for the water to flow to the north. An averaged advection path around the Scotia Sea (Fahrbach et al., 2001) following the continental rise of South America towards the Rio Grande Rise amounts to ~6,500 km. Assuming a travel time of roughly 65 years between 1925 and 1990 we can estimate an averaged speed for the arrival of the temperature anomaly at the Rio Grande Rise of ~0.3 cm s^{-1}, a number which appears to lie in a realistic range of magnitude.

Finally, the latest section of potential temperature across the Vema Channel from November 2002 (Fig. 2) shows that the cold jet on its eastern flank became substantially wider than earlier observed (Hogg and Zenk, 1997) or its width may change periodically. We do not have enough cross-stream data to speculate on this problem. However, changes in the temperature measured by moored sensors in the Vema Channel may also be associated with the fluctuations in the width of the cold jet.

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The WOCE global data resource: Lessons for CLIVAR data and data requirements

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WOCE data achievements

One of the most significant outcomes of the World Ocean Circulation Experiment has been the high quality oceanographic data that have been collected and assembled over the 1990's. It is these oceanographic data that will drive the basin-scale research for the next decade and will form the reference data sets for future global climate and climate variability programmes such as CLIVAR. The greatest legacy of WOCE could arguably be the oceanographic data from the 1990's.

The management of these data has been the role of the WOCE Data Management Committee and later the Data Products Committee. Although, the management of data is considered unexciting by many researchers, the systematic management of data sets is critical to making the data available to the oceanographic research community and of sufficient quality for analysis, synthesis and interpretation. No *single* research group or organisation could have developed and distributed the data from the WOCE field programme. The WOCE Global Data Version 3.0 (WOCE Data Products Committee 2002) is the final product created for the climate research community before the end of the WOCE programme in 2002. In excess of 90% of all the data collected during WOCE is available to the general research community (Fig. 1). These data are also available online and the holdings of each of the participating Data Assembly Centres has been archived with the NODC.

Thus WOCE completed the task that it set for itself of the management and delivery of high quality data to the oceanographic research community. This task has evolved from establishing standards for data (for example CTD measurements, analysis of water samples, tracers, nutrients), the development of better processing methods (e.g. chemistry and XBTs), and the quality control of the data by scientists with expertise to a role more focused on the delivery of uniformly formatted and described data to the worldwide web, CD ROMS and DVD's. These products have involved greater integration of the different data streams by increasing the standardization and consistency of naming conventions across data sets, through the use of self-describing data formats, development of tools capable of searching over spacio-temporal information and variables, the delivery of data directly to applications such as Matlab, Ferret, and standard programming languages and products for quickly viewing WOCE data such as eWOCE (Schlitzer, 2002).

None of these outcomes would have not been possible if the WOCE planners had not made the strategic decisions that encouraged resources to be allocated towards data management including tracking of the observations, and without the willing and active participation of science users as well as scientists at the WOCE Data Assembly Centres.

WOCE data resource, problems and innovations

The WOCE Data Resource consists of 18 different elements distributed across the globe managing and quality controlling the 12 different observational data streams. A Data Information Unit tracked the progress of the WOCE field programmes and gathered the necessary field information to ensure that the data assembly centres were receiving data and were aware of the data sets were being collected by WOCE investigators. The data assembly centres were mainly divided by instrument type and always had a close association with scientists using these data streams as active research users (Fig. 2). The 12 data streams consisted of the

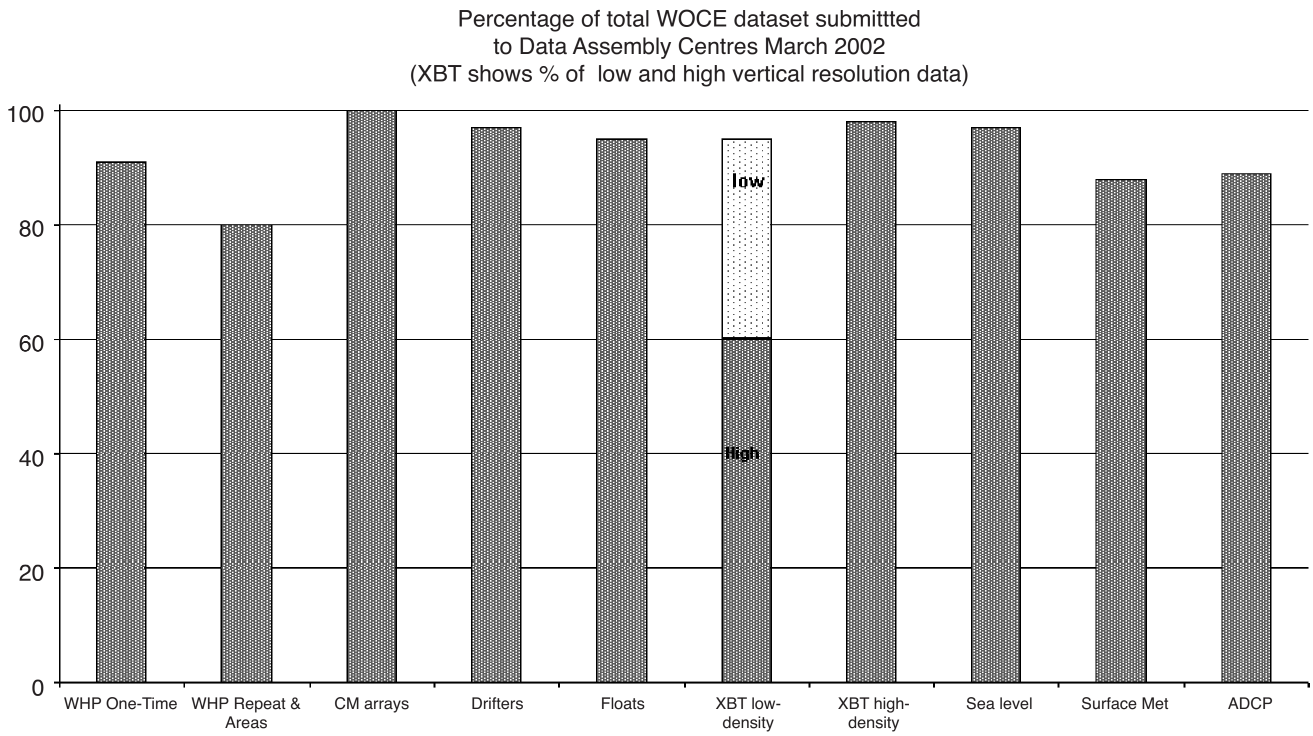

Fig. 1: Percentage of WOCE data actually gathered by investigators and available from the WOCE the insitu field programme.

hydrographic programme, surface drifters, upper ocean thermal data, sea-level, subsurface floats, moored measurements, surface meteorology/air-sea flux, surface salinity, satellite altimetry and sea-surface temperature (which was later expanded to include satellite surface winds), bathymetry, acoustic doppler current profiler, and the WOCE data archive (Lindstrom and Legler, 2001).

The principal role of each data assembly centre was to gather data from the participating investigators, to undertake quality control, and assemble the relevant metadata and include relevant reports from investigators providing the data. The individual DACs then provided the research users access to the data (subject to data policies) as well as value-added products in a DAC specific standard format (collectively the DACs agreed to a more standardized format to achieve greater consistency and uniformity). The DACS heavily involved the investigators, in clarifying the data and its associated metadata, which in some cases turned out to be time consuming depending on the particular data set and its complexity. Some of the Data Assembly centres also undertook the integration of different data types. For example the hydrographic data assembly centre combined all the different water sample analyses (including CFC's, stable and unstable isotopes measurements each performed by different research groups) into a single file. From a researchers perspective, the data assembly centres provided a single point of contact for each WOCE data stream representing literally thousands of participating data providers.

Innovations

A major innovation of the WOCE field programme was the creation of individual Data Assembly Centres (DACs) that were closely aligned with expertise in the analysis of data. A second innovation was to establish the Data Information Unit (DIU) to track the field programme and investigators contributions. These two features required the WOCE data resource to be geographically distributed (as shown in Fig. 1). By encouraging support for these activities at the national and international levels, it has been possible for each DAC to adapt to the rapidly evolving technology associated with the World Wide Web, CD-ROMS, and DVDs. The World Wide Web has allowed each DAC to establish itself as an organisation, to document its progress and to continuously update and deliver their data holdings to the wider research community, thus developing a broader user market

The world wide web also allowed the DACs and DIU to interact with each other, and make initial steps to re-integrating the WOCE field programme into a whole, rather than as a small number of dis-aggregated data streams. This flexibility, was important, considering that the WOCE field program was conceived long before the World Wide Web became an everyday commodity. By refocusing of the management committee in the mid 1990's to have a greater orientation on the delivery of *products*, the DACs had greater freedom to deliver their own products as well as producing the WOCE Global Data V 1.0, 2.0 and 3.0 for distribution to scientists and libraries all over the world. The introduction of a stand-

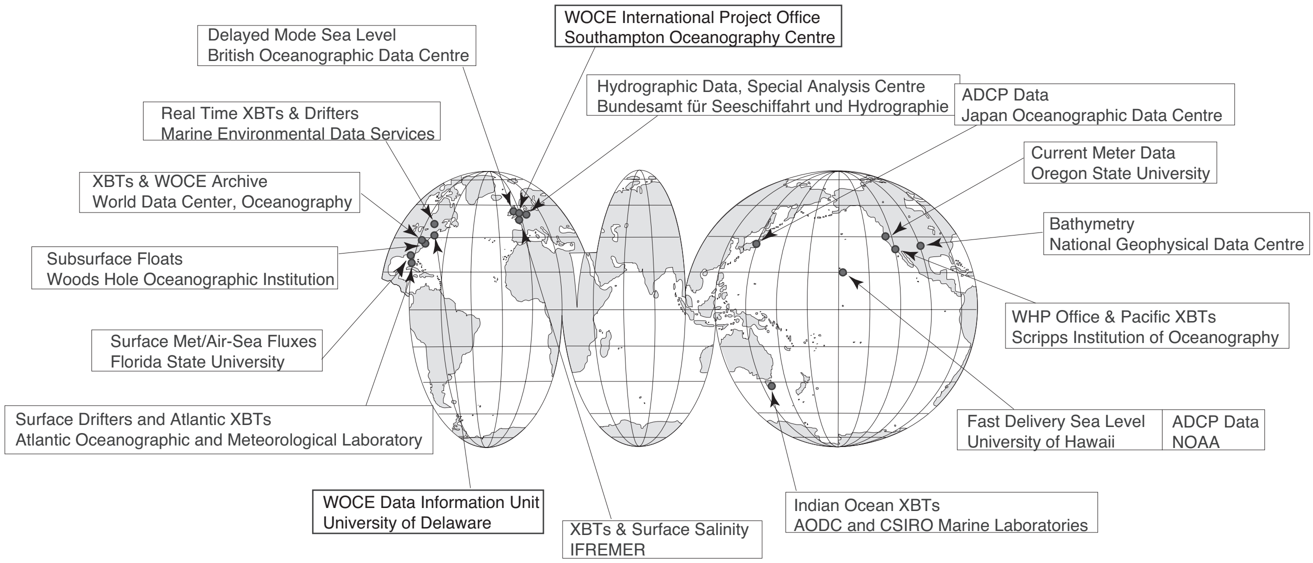

Fig. 2: WOCE Global Data Resource showing the different groups that were involved in the 12 data streams and tracking the WOCE Field Programme (eg Data Information Unit). Some data streams (XBT's) had more than one Data Assembly Centre.

ard naming conventions (e.g. COARDS/WOCE convention) and agreement to utilize self describing data formats across all data streams is a particularly important innovation for researchers who are interested in combining and synthesizing the many different data types into a single study. Self-describing data sets explicitly include relevant metadata (e.g. units, the size of the data sets, the variable names, and other information such as the originator, the principal investigator). Consequently, these data sets are more robust against common programming mistakes. This standardisation also means that once researchers have established the skills needed to read one WOCE data stream, they can readily read and integrate all 12 data streams. Without such a standardisation many of the small research groups and individuals simply could not afford the resources to read and sort the different data streams from the WOCE Global Data for synthesis. Finally by choosing self-describing data formats, WOCE opens the door for newer and more dynamic data access methods that could seamlessly and easily deliver WOCE data over the web directly to applications. Protocols such as Distributed Oceanographic Data Servers (now called Open Data Access Protocol) are ushering in a new paradigm of virtual data access that facilitates the seamless (and hidden) gathering of data from multiple servers.

Lessons from WOCE

The WOCE Data Resource is not perfect. There are overheads created by being distributed, which with the world wide web and emerging new technologies have been or will be largely overcome. Although, imagining how communication between DAC and investigators was to be achieved must have been daunting task at the inception of WOCE Data Resource.

The distributed data system with each data assembly centre representing a single data type can also have particular problems. For example, if one wanted to combine ADCP data and hydrographic data and surface meteorology data from a single WOCE hydrographic section then the data would have had to be retrieved from three different DACs and merged by the individual researcher. For some data types, aggregating the WOCE data streams to enable joint analysis presents special problems as the relationship between the different variables can be obscured and even lost through the distributed system. WOCE allowed for this by the use of unambiguous experiment codes that were assigned to all the data collected on a single voyage. For programs like CLIVAR careful thought must be given to how the different data streams should be organized. On balance, for WOCE, the distributed data system based on data type has been advantageous to research using only a single data type (for example hydrography) but does present disadvantages to those trying to integrate the data types by individual researchers.

Because WOCE was a relatively long term experiment, there have been significant observational technological developments (Davis and Zenk, 2001; King et al., 2001). The development of the profiling subsurface drifter (so-called PALACE that are being further developed and deployed by the Argo programme) and lowered ADCP (LADCP) are two examples of technological developments that have lead to significant new capabilities for observing the ocean. Both of these technologies were readily adopted by investigators and incorporated into the overall WOCE field programme. However, neither PALACE profile nor LADCP currents data were fully incorporated into the WOCE data resource as originally planned and funded. Consequently, it took several years to develop a plan and establish the resources for the inclusion PALACE profile data into the WOCE Global Data V3.0. The resources needed for the inclusion of the LADCP into the final WOCE data set were never secured. Thus, WOCE had mixed success in managing new instrument types into the WOCE Data Resource, mostly because of the difficulty of securing the necessary resources to establish a new Data Assembly Centre to manage the new data. In CLIVAR, a programme expected to run 2 or more decades and with an even more diverse array of data types, there are bound to be many new instrument types which will lead to data streams that have to be managed and quality controlled. This implies that the CLIVAR data system will need to be flexible, being able to fund or secure resources from different organisations that will actively participate and support each new instrument type.

While adopting standards for naming conventions and data formats can lead to very significant savings for researchers in their work, these standards introduced new work on each of the DACs to comply with the WOCE conventions. This overhead was forced on each DAC. The key skill of the DACs was their expertise with the observational data and products more so than their expertise in network-aware, self describing formats and the developments of metadata standards (e.g. naming conventions) and management. It would have been advantageous if the WOCE Data Information Unit also included expertise in these areas. Such a resource would have helped the DACs to continue adapting their data holdings to current data managements standards and practices . Finally, this expertise must be an integral element of the CLIVAR strategy because its data system must be capable of responding to researchers who will require access to (ocean, atmospheric, hydrological, cryospheric) data from the research programme, as well as data from operational systems and products from models, assimilation, and forecast systems.

Finally, one of the most common criticisms of the WOCE data system was the delay in availability of data. This delay was chiefly the by-product of a two-year data embargo held by Principal Investigators and in part by the time taken to quality control data for some of the data streams. The WOCE data, particularly those data streams that come from *in situ* measurements, are rich in complexity and have subtle nuances often requiring human intervention and assessment. Now that principal investigators have accepted the need for reduced delays and near real time availability of their data, and perhaps with improved automation of quality control, it will be possible to provide quality controlled data with less delay. However, the concept of continuously managed data sets where real-time data are replaced at a later date with the quality controlled version of the data set is only undertaken in the upper ocean temperature DAC and to a limited extent at the Hydrographic Programme Office. Some data sets (perhaps incomplete or of less-than-perfect quality) are critical for real-time forecasts of the oceans and atmosphere; for climate applications where the signal is small, quality control is likely to matter more. CLIVAR has distinct needs for both "types" of data and will emphasize that researchers must be able to discern important data qualifiers such as these.

Data management needs for CLIVAR

There are very significant differences between the CLIVAR programme and WOCE field programmes. The differences result largely from the scientific scope of the CLIVAR programme and the extraordinary range of disciplines involved in CLIVAR. WOCE was principally an ocean only programme, focused on the physical aspects of global circulation. Most of (but not all) of the WOCE data streams (Fig. 2) were created for the WOCE programme in order to achieve its goals of understanding the large scale circulation and its variability. The broad scientific scope of CLIVAR, including variability over seasons to decades and longer means that many of the data sets required for the science streams of CLIVAR will necessarily build on data/data products provided by third party organizations that were created with other scientific goals or missions (e.g. ARGO, and weather forecasts from NWP centres etc.) and are resourced separately. So the CLIVAR data system will be more dependent on external data providers. However, like WOCE , CLIVAR will however need high quality data to detect the relatively small signals, and these data will be required from multiple disciplines and sources.

Because CLIVAR is envisaged to have a longer duration, some of the problems that occurred during the WOCE field programme will be magnified. The CLIVAR data system will have to cope with the irregularities of funding at national and international levels which will impact on the various data streams (e.g. some DACs may close and new ones open). New technology will mean that the data streams will change over time, and mean that new resources will have to be created or redirected to ensure that there are no data orphans. There will be a greater need for leverage of other organisation's resources to obtain data (remote sensing, ECMWF re-analysis products, etc.). There will be significant challenges in meeting the near real time requirements of the various data streams. For many field oceanographers this means that data will have to be delivered to DACs quickly. This requirement, means that CLIVAR's data system has to be operational before CLIVAR field programmes become very active. Many nations have started their CLIVAR field programmes and so the information about these activities needs to be tracked now. This implies a Data Information Unit that is operating effectively now.

Additionally, CLIVAR needs to assure the quality and full characterization of the data it requires in order to fully ascertain and describe the significance of scientific discoveries, justify new observing systems, and support decisions based on the data and derived products (e.g. forecasts). WOCE focused on instrument-based quality evaluations, but much more rigorous quality

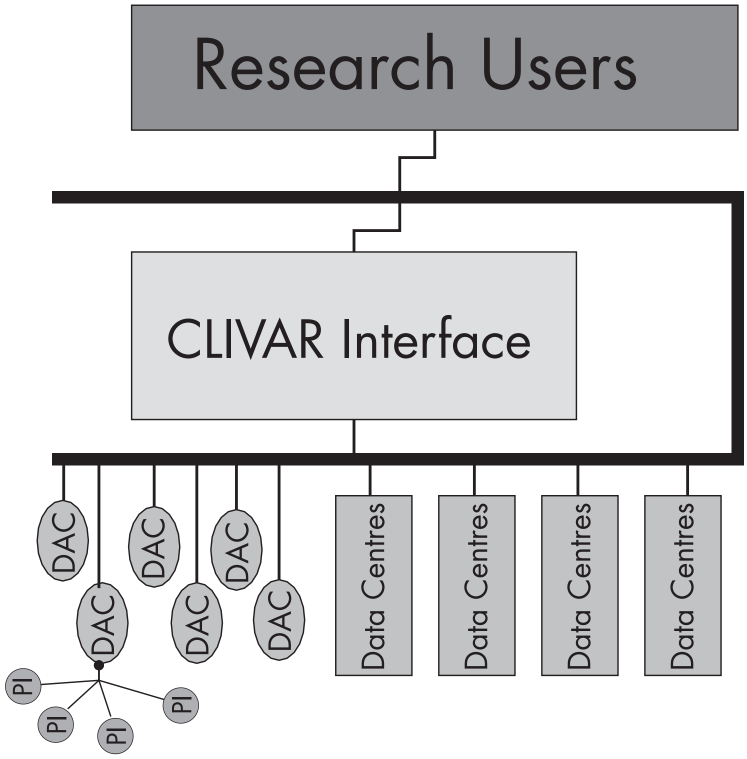

Fig. 3: Functional units of the CLIVAR Data Resource showing the flow of data. A hybrid data management system of principal investigators, WOCE style data assembly centres, national weather centres and organisations providing key data sets to CLIVAR researchers. The CLIVAR interface tracks the field (and modelling) programmes and provides services to DACs and users to support the use of CLIVAR data.

evaluations can be achieved through the interpretation of the uses of observations. Models, data assimilation and forecast systems provide information on data quality (which need careful scrutiny). These systems should be incorporated into a robust data management system. Additionally, observational quality can be assessed through data-to-data and data-to-product comparisons (e.g. *in situ* vs remotely-sensed SST, or surface drifter atmospheric pressure vs. pressure fields from space borne scatterometers). CLIVAR must advance the integration of these evaluation approaches as part of its programmes in advance, because ultimately observational data will be evaluated in the context of such a multivariate framework.

How CLIVAR should build from the WOCE data resource

The CLIVAR programme has had difficulty coming to grips with the scope and range of data requirements implied by the three scientific streams. Partly because of the differing needs and requirements of scientific disciplines involved in the programme. For example, oceanographers have a rich tradition of collecting their own specific data sets, and analysing them in relative isolation. The WOCE Data Resource was the first data management system designed for oceanographers and their requirements. In contrast, meteorologists tend to have a well established observing and data systems, devoted to the needs of creating forecasts and analyses, and these systems do not need re-inventing but may require tuning to address the more stringent needs of CLIVAR.

The CLIVAR data resource should be considered as a hybrid system (Fig. 3). It should include aspects of the WOCE data management system, in particular for the oceanographic data sets. Where data are collected by many individual scientists, there should be DACs with the scientific skills to assess and assemble these data and provide them to the wider research community as a part of an integrated data management system. The CLIVAR data resource is therefore distributed. The key data sets and products that meet the needs of the CLIVAR programme (remotely sensed, weather prediction centres, ARGO etc.) must be assured.

To facilitate the delivery of the data to researchers CLIVAR must insure there will also be a *CLIVAR Data Interface (CDI)*. The CDI (which is a rubric for a collection of activities) could facilitate accessing, querying, and retrieving metadata as well as data and products. One critical element, the metadata unit, would be analogous to the original WOCE DIU, but with an expanded role to track CLIVAR field programmes (and its principal investigators) and also insure the CLIVAR data system is linked and consistent with other organizations that are providing CLIVAR related data. The CDI would also work with CLIVAR DACs (established as the interface between research observation systems and the research community) and participating organizations to help the standardization of the many differing input data streams at the bottom of Fig. 3. It would also develop; in consort with similar efforts, metadata, suitable data quality systems, and standards for distributed servers and access protocols. The CDI is thus in some sense a gateway for data, information, and products provided and needed by CLIVAR. However the interface is not a repository for data. Rather, the CDI would address and enhance capabilities to find and access data, thus removing some of the burden on the data providers in meeting the CLIVAR data needs. The system needs to be robust to failure or bottlenecks that could develop, and so should not be the exclusive means by which CLIVAR researchers can obtain data.

Overall, it estimated that the WOCE devoted less than 10% of its overall resources total to the management of data. This is a small explicit cost, compared with the hidden cost to research groups of duplicating effort in their attempts to synthesize the WOCE data. Much was leveraged from national organizations, particularly in the latter years when other funding sources ramped downwards. Many of the same organizations (and DACs) with their skill and expertise are keen to be involved in CLI-

VAR. Because of the complexity of the climate system, crossing discipline boundaries and requiring the integration of disparate data sources, it is even more important for the CLIVAR programme to develop a strategy for a well managed data system to succeed in its stated goals.

Acknowledgements

The support of all the WOCE DAC/SAC managers, members of the WOCE DPC, national oceanographic organizations and funding bodies involved in the WOCE Data Resource is gratefully acknowledged.

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6th session of the JSC/CLIVAR Working Group on Coupled Modelling (WGCM)

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The sixth session of the JSC/CLIVAR Working Group on Coupled Modelling (WGCM) was kindly hosted by the Canadian Centre for Climate Modelling and Analysis (CCCMA) and held in the Laurel Point Inn Hotel in Victoria, Canada, from 7-10 October 2002. The session was partly (9 - 10 October) held jointly with the IGBP GAIM (Global Analysis Interpretation and Modelling) group.

Main foci of the meeting were:

- Discussion of the WCRP Banner Proposal
- Next phases of the CMIP Project
- Launch of an intercomparison of cloud feedbacks in models / Idealized experiments
- Detection and attribution of climate change
- Developments within PMIP
- Interactions with GAIM

Discussion of the WCRP banner proposal

In welcoming the banner initiative, WGCM formulated a number of comments for consideration by the JSC for WCRP in terms of the development of the banner and its scope.

Next phase of the CMIP project

CMIP (http://www-pcmdi.llnl.gov/cmip/) is one of the most important and long-standing initiatives of WGCM, having been started in 1995. There are now three components: CMIP1 to collect and document features of global coupled model simulations of present-day climate (control-runs); CMIP2 to document features of control runs and climate sensitivity experiments with CO_2 increasing at 1% per year; CMIP2+, as CMIP2, but many extra fields and data, and monthly means, and some daily data are being collected.

WGCM recommended starting a pilot project on Coupled Model Climate of the 20th Century experiments which should be announced through CMIP. There was an agreement on a set of diagnostics. Furthermore it was pointed out that since no single forcing is prescribed for these runs, a comprehensive documentation of the forcing is required. One use of these runs is likely to be in detection and attribution studies.

Two sets of CMIP experiments are currently under way to better understand the North Atlantic THC's response in AOGCM's: a) sensitivity of the THC to heat and water flux forcing and b) so-called 'water hosing' experiments.

WGCM noted that it would be very useful if a set of indices were developed to document important modes of variability in the coupled system. Model results could then be compared using these indices. This would provide a simple, clean way of evaluating model performance.

WGCM felt that the Modelling Intercomparison Projects (MIPS) should in time be more integrated towards an Earth System Modelling umbrella. The Coupled Model Intercomparison Project (CMIP) could serve as the overarching MIP. A more detailed summary about CMIP can be found in the electronic supplement of this newsletter.

Launch of an intercomparison of cloud feedbacks in models / idealized experiments

In recent years, WGCM has undertaken an initiative entitled "idealized sensitivity experiments" involving intercomparisons of results from equilibrium doubled CO_2 experiments, in which the atmosphere was coupled to a slab ocean, thus not involving the complexity of the full ocean response. This work has shown significant differences in inferred cloud forcings and changes in top-of-the atmosphere fluxes in different models and had been drawn upon in the IPCC Third Assessment Report (TAR).

The scientific community had expressed considerable interest in continuing this study and various means for diagnosing feedbacks. At the previous session WGCM endorsed a proposal, put forward by Drs B. McAveney and H. LeTreut, for systematic intercomparison of cloud feedbacks in climate models in the approach to understanding climate feedbacks. The authors presented a strategy to implement this project which was endorsed by WGCM. A letter of invitation for participation has been sent out and is also available through the CLIVAR website.

Detection and attribution of climate change

Dr. G. Hegerl summarized for WGCM the range of outstanding issues with respect to detection and attribution of climate change. She started with some results from a multi-signal detection technique also used for the IPCC TAR. The method generally considered the most rigorous and powerful for this purpose was the multiple regression technique, "optimal fingerprint detection". Ideally, these methods require ensembles of simulations of twentieth century climate with individual forcing agents to provide "fingerprints", and very long (multi-centennial or even millennial) control simulations to assess internal climate variability. Several groups have used this approach, with strong indications of anthropogenic influences on surface temperature being found: the results from different groups were consistent and inter-implementation differences small. The technique could also be employed to scale simulations of the twenty-first century to infer predictions of mean temperature change relative to twentieth century observations and to estimate key parameters such as climate sensitivity, ocean heat uptake and sulphate aerosol forcing.

Dr. N. Gillet reported on detection of anthropogenic influence on temperature and sea level pressure (SLP) with a multi-model ensemble. The results showed that multi-model detection provides a way to synthesize results from different models and reduces the uncertainties in a simultaneous detection of greenhouse gas and sulphate effects on surface temperature. This is at least partly due to the larger ensemble sizes and longer control available. Modelled and observed SLP trends show a decrease over the Arctic, Antarctic and N. Pacific, and an increase over the subtropical N. Atlantic. The greenhouse gas + sulphate aerosol response could be detected in sea level pressure but the SLP changes simulated in response to greenhouse gas + sulphate aerosol forcing are significantly smaller than those observed.

Palaeo-climatic modelling

Dr. P. Braconnot reported on recent developments in the area of paleo-climatic modelling, and in particular the Palaeoclimate Modelling Intercomparison Project (PMIP) (http://www-pcmdi.llnl.gov/pmip/). The PMIP panel met in Cambridge, UK, June 22-27, 2002 and defined research priorities for the next phase of the PMIP project.

In its initial phase, designed to test the atmospheric component of climate models (atmospheric general circulation models: AGCMs), the project focused on the last glacial maximum (LGM: ca 21,000 years before present, 21 ka BP) and the mid-Holocene (6000 years before present, 6 ka BP). The results of this study formed a crucial part of the evaluation of climate models in the IPCC TAR.

PMIP has not confined itself only to analysing and evaluating the benchmark LGM and mid-Holocene experiments. Complementary experiments, examining the role of the ocean and of the land surface in past climate changes, were also carried out by several of the participating groups. Perhaps one of the most important conclusions emerging from the first phase of PMIP was the importance of including ocean and vegetation feedbacks in model simulations in order to simulate the regional patterns and magnitude of past climate changes correctly. Largely as a result of this realisation, PMIP created a working group to design protocols for palaeo-experiments using fully coupled models. The coupled experiments comprise:

- coupled ocean-atmosphere (OAGCM) and ocean-atmosphere-vegetation (OAVGCM) simulations of the response to mid-Holocene (6 ka BP) insolation changes
- coupled ocean-atmosphere (OAGCM) and ocean-atmosphere-vegetation (OAVGCM) simulations of the response to glacial conditions (21 ka BP experiment)

WGCM welcomed this new activity and encouraged PMIP to proceed and to further cooperate with groups within WCRP and IGBP, such as CMIP, PAGES/CLIVAR and GAIM, as appropriate.

Interactions with GAIM

The second part of the WGCM meeting was held jointly with the IGBP GAIM (Global Analysis Interpretation and Modelling) task force. Both panels agreed to foster their cooperation on various sectors. Joint leadership of the Coupled Carbon Cycle Climate Model Intercomparison Project was considered. Furthermore, WGCM and GAIM will collect information about the different MIPs. Each MIP will be asked to submit a short summary and some key references. A preliminary catalogue is available under http://www.clivar.org/science/mips.htm.

Another area of interaction is the atlas project initiated by GAIM. The overarching goal is to publicize as broadly as possible the results of global change research in the form of an atlas. Specific objectives are to establish a single source of information that has undergone peer review, to present the research results in an easily understandable form, provide updates, enable superpositions of various data sets, link maps and time series with original data, and identify conceptual and data gaps that will need to be filled by the scientific community through the development of new research projects. Data sources will include both ground based and remotely sensed data. WGCM is well versed in data management through its PCMDI activities, and could contribute significantly to the atlas effort. In order to foster the cooperation, both groups agreed that future joint meetings should be considered. One possibility is a two-year schedule, in which GAIM meets with WGCM and a relevant component of IHDP in alternating years. WGCM will meet next time September 24-26, 2003 back-to-back to the International Earth System Modelling Conference and the CMIP workshop in Hamburg, Germany.

7th session of the CLIVAR Working Group on Seasonal-to-Interannual Prediction (WGSIP)

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The 7th session of the CLIVAR Working Group on Seasonal-to-Interannual Prediction (WGSIP; previously known as CLIVAR NEG-1) was held at, at the University of Cape Town, Cape Town, South Africa, 19.-22. November 2002. Prof. Chris Reason from the University of Cape Town served as the local host for the meeting. Dr. Steve Zebiak chaired the session and welcomed the working group members, invited experts, and local participants.

Main foci of the meeting were:

- Review of related activities over the past year
- Definition of ENSO scale
- Launch of the WGSIP standards project
- Review of other WGSIP projects and cooperation with other programmes

Review of related activities over the past year

The working group reviewed the activities of related CLIVAR and WCRP groups, such as WGCM, WGNE, CLIVAR SSG, and other CLIVAR panels as well as national and multinational modelling projects relevant to WGSIP.

A major point of discussion in this context was the proposed 'Banner on Predictability', presented at the last session of the Joint Scientific Committee of WCRP. WGSIP formulated a number of comments for consideration by the JSC for WCRP in terms of the development of the banner and its scope.

Definition of ENSO scale

The CLIVAR SSG has asked WGSIP to address the problem that no widely accepted definition of El Niño exists. Within the scientific community, the definition by Trenberth (Trenberth, K. E., 1997: *Bull. Amer. Meteor. Soc.*, **78**, 2771-2777) is often used. The main disadvantage of this definition is that it requires 12 months of data before an El Niño can officially be declared. The working group argued that a widely used definition of El Niño should have a real-time benefit. Based on a study of the characterization of ENSO using a multi-index approach, it was concluded that the NINO3.4 index contains the basic information on the state of the tropical Pacific Ocean as it affects ENSO and relates to global climate. The working group discussed potential definitions based on the NINO3.4 index in depth. Major issues were potential categories, averaging (base) periods to be defined and used in an index definition and whether or not a definition should characterize the phenomenon in terms of impacts or not. The WG agreed on the definition of a continuous numerical oceanic El Niño index (OENX), based on the NINO3.4 index, which is intended to characterize the state of the tropical Pacific as it relates to ENSO, but which avoids "categories". While such an index does not directly address local and remote climatic impacts, it does provide a common framework within which regional categorical or other impacts-related interpretations can be based. A definition drafted at the meeting will be circulated to the CLIVAR SSG in the near future.

Launch of the WGSIP standards project

This new activity had been initiated by WGSIP two years ago. During the past year a proposal for a first stage of such a project on the exchange of long range forecast (LRF) verification information was written by the Commission for Basic Systems (CBS) Expert Team on LRF Verification (based on a an earlier proposal written by Drs. M. Harrison and N. Nicholls). WGSIP reviewed and discussed the CBS proposal.

WGSIP endorsed the CBS Report on verification of long-lead forecasts, regarding it as an excellent starting point for a WGSIP project. Nevertheless, the CBS proposal was regarded as a minimum baseline that does not include enough diagnostics for WGSIP purposes.

Thus, WGSIP agreed to start a long-term evolving project on Standardised Verification Sets (SVS) for long-range forecasts based on the CBS protocol. In order to keep the project manageable and affordable, the group favoured a distributed system guided from a central website. Furthermore, the group preferred that the location and handling of this website should be done through CLIVAR, i.e. the ICPO. WGSIP recognized that this task goes beyond the present resources of the ICPO. Therefore, the group will ask CLIVAR to seek resources to build up such as system. In addition, other mechanisms to implement this project are being explored.

Review of other WGSIP projects and cooperation with other programmes

1. Seasonal Prediction Model Intercomparison Project (SMIP)

The working group discussed ways to encourage participation in SMIP2 and to expand the project to encompass the range of research and operational approaches currently being used by the SIP community. It was decided that this could be accomplished by accepting a broader range of initial conditions for the forecasts. The SMIP web-page (http://www-pcmdi.llnl.gov/smip/) will be modified and groups will be alerted to these extensions and modifications to the SMIP2 protocol by email.

A SMIP Panel (G. Boer, M. Davey, I.-S. Kang, K. Sperber) will identify potential participants, promote the project, guide analysis, and encourage and coordinate diagnostic subprojects. A deadline for submission of SMIP2 data is proposed for July 2003 in order to enable preliminary analysis in time for the next session of WGSIP.

2. Review of climate events over the past year

The WG reviewed a number of exceptional climate events of the past year, such as monsoon drought over India, El Niño impacts in Australia, wet conditions in SE South America, Sahel drought, etc.) and the ability of seasonal forecast products to capture these events. Some positive results were noted for events related to the present ENSO conditions, while other events were not correctly predicted.

3. Interaction with GEWEX GLASS

WGSIP aims to strengthen its link with other relevant modelling efforts, in particular with those encompassing land surface processes. Thus, Dr. R. Koster was invited to join the group as a new member and liason to the GEWEX programme. Dr. Koster reported on two activities of the GEWEX GLASS (Global Land Atmosphere System Study), which have significant overlap with WGSIP objectives:

1. "GLACE" (Global Land-Atmosphere Coupling Experiment) is a broad follow-on to the four-model intercomparison study described by Koster et al. (*J. Hydrometeorology*, *3*, 363-375, 2002).

2. "Poor-Man's LDAS": The aim of the project is to study the impacts of soil moisture initialization on seasonal forecasts.

WGSIP welcomes and endorses the GLASS project GLACE (Global Land-Atmosphere Coupling Experiment) as a joint cosponsored activity of GLASS and WGSIP. WGSIP expressed its interested to be involved in the discussion and planning of other GLASS activities, such as the Poor-Man's LDAS.

4. Local presentations

The working group wishes to foster the cooperation and exchange with scientists active in the field of seasonal prediction. WGSIP was very pleased, therefore, to hear a number of local presentations led by Prof. C. Reason that provided a comprehensive overview on climate research in South Africa.

The full report of the meeting will become available through the WGSIP webpage (http://www.clivar.prg/organizazion/wgsip/) soon.

Meeting announcement:
International Conference on Earth System Modelling -Sept. 15-19, 2003, Hamburg, Germany

Four years after the 4th International Conference on Modelling of Global Climate Change and Variability, we are pleased to invite the scientific community involved in earth system research to meet in Hamburg. The conference addresses global, regional and reduced complexity modelling. It will provide an opportunity to present new results in this field and to discuss recent developments and plans for the future.

The Programme Committee invites contributions on any of the following subjects (in parenthesis you find the names of the invited key speakers):

A. Development and Evaluation of Comprehensive Earth System Models (Berrien Moore III)

1. Atmosphere, Oceans and Sea-Ice (Jochem Marotzke)
2. Atmospheric Chemistry (Ivar Isaksen)
3. Biosphere in the Climate System (Nathalie deNoblet-Ducoudré)
4. Modelling Paleo-Environments (Pascale Braconnot)
5. Data Assimilation and new Earth System Data Sets (Dave Easterling)
6. The Human Dimensions in the Earth System (Carlo Jaeger)

B. Variability of the Coupled Earth System at Different Time Scales (Tim Palmer)

1. Seasonal to Interannual Time Scales (Mark Cane)
2. Decadal to Centennial Time Scales (Ronald Stouffer)
3. Changes in Variability Modes as seen in Records and Modelling Studies of Past Climates (Tom Crowley)

C. Anthropogenic Climate Change (John Mitchell)

1. Detection and Attribution (Gabriele Hegerl)
2. Climate Change Prediction (Filippo Giorgi)
3. Simulation of Historical Climates (Drew Shindell)
4. Greenhouse Gases, Aerosols, Land Use Change in the Present, Past and Future (Sandy Harrison)
5. Assessing the Risk of Extreme Events and Singularities (Andreas Hense)
6. Integrated Assessments (Joseph Alcamo)

A preliminary programme of the contributed and invited papers will be distributed in the 3rd Circular in summer 2003. The deadline for abstracts (camera-ready) is 15 March 2003.
For for further information with respect to registration and abstracts, please contact Dr. Annette Kirk, Conference Coordinator, Max-Planck-Institut für Meteorologie, Bundesstr. 55, D-20146 Hamburg, Germany,
e-mail: annette.kirk@dkrz.de.
or http://www.mpimet.mpg.de/mpi-conference2003/

CLIVAR Calendar

2003	Meeting	Location	Attendance
March 31-April 3	International Symposium on Climate Change (ISCC)	Bejing, PR China	Open
April 7-11	European Geophysical Society (EGS) XXVIII General Assembly	Nice, France	Open
April 13-15	Working Group on Ocean Model Development, 4th Session	Villefranche, France	Invitation
April 13-14	CLIVAR Atlantic Implementation Panel, 5th Session	Villefranche, France	Invitation
April 23-26	CLIVAR VAMOS Panel, 6th Session	Miami, USA	Invitation
May 6-9	CLIVAR Scientific Steering Group, 12th Session	Victoria, Canada	Invitation
June 16-20	18th Stanstead Seminar: Climate Variability and Predictability from Seasons to Decades	Lennoxville, Canada	Limited
June 30-July 7	XXIII General Assembly of the International Union of Geodesy and Geophysics	Sapporo, Japan	Open
July 14-16	Pacific Implementation Panel, 2nd Session	Yokohama, Japan	Invitation
Sept. 8-12	CLIVAR/Clic Southern Ocean Panel, 2nd Session	Bremerhaven, Germany	Invitation
Sept.15-19	Intl. Conference on Earth System Modelling	Hamburg, Germany	Open
Sept. 22-23	CMIP Workshop	Hamburg, Germany	Limited
Sept. 24-26	Working Group on Coupled Modelling, 7th Session	Hamburg, Germany	Invitation
Oct. 11-16	2nd Euroconference "Achieving Climate Predictability using Paleoclimate Data"	S. Feliu de Guixols, Spain	Open

*Check out our Calendar under: **http://www.clivar.org/calendar/index.htm** for additional information*

Contents

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